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DTU Aqua
National Institute of Aquatic Resources

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In co-operation with the Danish Fishermen's Association

Ministry of Food, Agriculture and Fisheries

European Fisheries Fund

European Fisheries Fund: Denmark and the EU investing in sustainable fisheries

DANMARKS FISKERIFORENING

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Abstrakt (Danish abstract)

Viden om den geografiske fordeling af fiskebestandene gennem året får central betydning for alle fremtidige former for forvaltningsplaner og -redskaber. Oskar projektet viser hvordan det er muligt at udnytte den samlede geografiske viden til at optimere fiskerierne i Skagerrak og specielt undgå uønsket bifangst af torsk og uberettiget lukninger af områder. Kernen i projektet er et nyt geostatistisk værktøj (GeoPop modellen), som specielt udnytter forskellige togt data til at forudsige hvordan den geografiske fordeling af alle størrelser torsk i havet (populationen) har været i perioden. GeoPop er også i stand til at bestemme variationen indenfor det enkelte træk. Denne småskala variation har vist sig at være af betydeligt omfang, hvilket understøttes af en stor variation i næsten samtidige fangster af ungtorsk på nabostationer i Oskar togterne. Det er således dokumenteret videnskabeligt at de nuværende kriterier for Real Time Closure (RTC) er uberettigede, fordi ungfisk er så klumpet fordelt, at fangsten i ét trawltræk ikke direkte kan bruges som mål for den lokale tæthed.

Resultaterne fra Oskar projektet viser også hvordan man vil kunne forudsige fordelingen af ungfisk på en større geografisk skala flere år frem i tiden og dermed planlægge en optimal fordeling af fiskeriet og brug af specielt designede trawl til at undgå bifangster af fisk under passende markedsstørrelse. En årlig monitering af den geografiske fordeling af 0-1 årige torsk i Skagerrak vil også bidrage centralt til en forbedret bestandsvurdering.

Det er nødvendigt at udnytte den samlede tværfaglige viden om dynamikken i arternes geografiske fordelingsmønstre indenfor og mellem år. De tilsyneladende simple spørgsmål ”Hvor er fisken og hvorfor?” er komplicerede, når forvaltningen kræver viden på så lille en skala i rum og tid som det enkelte trawltræk repræsenterer. Fremadrettet er der behov for yderligere at integrere en samlet togt/moniterings indsats med indsamling og analyse af proces viden – en samlet data indsamling der optimalt bør fortsætte i en videreudvikling af fisker-forsker samarbejde baseret på dialog. Oskar projektet udgør det første skridt til en sammenkobling af fiskernes erfaringsbaserede viden, logbogs- og VMS-positions informationer, geografisk fordeling af artssammensætningen i fangster fra discard togter, viden om trawl selektion og selektive trawls, fangstdata fra et minimalt sæsonmoniteringstogt (fire Oskar surveys) samt forskernes moniterings- og procesbaserede viden.

Selvom GeoPop modellen er god til at ’udfylde huller i data i rum og tid’ er der et specielt behov for fremover at kunne udbygge indsamlingen af data på videnskabelige togter med en langt bedre udnyttelse af realtids data fra det kommercielle fiskeri. Det vil kunne implementeres med et Marint Data Center og specielt, hvis programmet for fuld dokumenteret fiskeri udbygges til sensor baseret fiskeri således at for eksempel temperatur rutinemæssigt måles på trawlet.

Sammenfatning (Danish synthesis)

Introduktion

Formålet med dette projekt er etablering af en viden om den geografiske fordeling af målarterne i Skagerrak gennem året, der gør fiskerne i stand til at tilrettelægge fiskeriet efter disse, således at fiskeriet er bæredygtigt med en minimering af udsmid og uønsket bifangst af torsk, og kan foregå uden drastiske reduktioner eller uberettiget lukninger af områder.

De demersale fiskerier i Skagerrak er et af de største danske fiskerier med en årlig landingsværdi på omkring 300 mill. kr. De er rettet mod en bred vifte af bestande, hvor de økonomisk vigtigste arter jomfruhummer, torsk, rødspætte og sej udgør ca. 70 % af den totale landingsværdi. Den demersale flåde domineres af trawlere med hensyn til såvel antal fartøjer og kilowatt-dage som landingsværdi. Jomfruhummer og sej landes udelukkende af trawlere, mens torsk fiskes af trawlere og garnbåde, og i mindre grad af snurrevodskuttere. Rødspætter landes hovedsaligt af snurrevodskuttere, men i en hvis udstrækning også af trawlere. Gennem de seneste årtier har den demersale flåde i Skagerrak undergået dramatiske ændringer med hensyn til antal af fartøjer og kilowatt-dage. Især har der været en betydelig nedgang i de torske-relaterede fiskerier i takt med at den dårlige status for torskebestanden har medført restriktioner i torskekvoten og begrænsninger i disse fiskerier. Resultat er at størstedelen af torsk (65-70 % i 2008-2010) landes i demersale fiskerier, der ikke er specifikt rettet mod denne art, hvorimod 60-80 % af jomfruhummer, rødspætte og sej landes i målrettede fiskerier. Indførelsen i 2007 af FKA (fartøjs kvote andele) i det demersale fiskeri medførte en koncentrering af torskekvoten til fartøjer, som i forvejen havde de største andele af kvoten i Skagerrak. Det afspejles i et mindre men voksende fiskeri med garn og snurrevod, der er målrettet efter torsk.

En bedre viden om den geografiske fordeling af bestandene gennem året af såvel torsk som de andre målarter er en vigtig forudsætning for optimering af fiskerierne under alle fremtidige former for forvaltningsplaner og -redskaber. Dels vil fiskeri i områder med uønskede arter og størrelser i højere grad direkte kunne undgås, og dels vil man bedre kunne designe selektive trawl (og andre redskaber), når man har en specifik viden om sammensætningen af de forskellige arter og størrelsesgrupper i et område med en vigtig målart, der ellers ikke ville kunne udnyttes på grund af for stor uønsket bifangst. I øjeblikket er der f.eks. krav om at der maksimalt må være i alt 10 % ungfisk af de forskellige torskefisk i forhold til den samlede vægt af torskefisk på trækbasis i trawlfiskerierne. Ved overskridelse af denne grænse lukkes et område midlertidigt for fiskeri: En såkaldt Real Time Closure (RTC).

Målet med dette projekt er med fokus på torsk at finde frem til hvilken viden om den geografiske og tidsmæssige fordelingsdynamik, der kan maksimere udnyttelsen af fiskeressourcerne i såvel de blandede som de målrettede fiskerier i Skagerrak, forstået således at fiskeriet er bæredygtigt med en minimering af udsmid og uønsket bifangst af torsk, og kan foregå uden drastiske reduktioner eller uberettiget lukninger af områder.

Metoder

Det overordnede mål blev forfulgt ved at kombinere resultaterne fra følgende arbejdspakker (Fig. 1):

Fiskerne: Erfaringsbaseret viden opbygget gennem deres årelange fiskeri (arbejdspakke A)

Fiskernes erfaringer med hvor de enkelte målarter befinder gennem året blev indhentet og systematiseret i et samarbejde med forskerne som en del af programmet på to workshops. Resultat er en række GIS-kort med områderne indtegnet for hver art med en tidsopløsning, der afspejler fiskernes opfattelse af dynamikken i den geografiske udbredelse for den enkelte art.

De demersale fiskerier (arbejdspakke B)

Den geografiske fordeling af effort, fangstrater og artssammensætning af landinger blev beskrevet for hvert kvartal i 2005-2010 ved at kombinere informationen fra logbøger med positions (VMS) data. Information fra discard togter blev brugt til at give et billede af den geografiske fordeling af artssammensætningen i *fangsten*. Den demersale flåde blev opdelt i flådesegmenter ud fra redskabstype og landingsprofil (artssammensætning), og udviklingen af den demersale fiskeflåde underlagt de skiftende forvaltningstiltag gennem det seneste årti blev beskrevet.

Trawl selektion og selektive trawls (arbejdspakke C)

De anvendte trawltyper i dagens fiskerier i Skagerrak og deres selektive egenskaber er beskrevet sammen med et bud på den fremtidige udvikling i trawldesign med henblik på de udfordringer der er for fiskerierne i Skagerrak. Desuden er eksperimentelt bestemte selektionskurver brugt til at konvertere den observerede størrelsesfordeling for de enkelte torskefisk i Oskar togterne (med 90 mm løft) til ditto i det kommercielle fiskeri med 120 mm masker (arbejdspakke D). Endelig er selektionskurver brugt i GeoPop modellen (arbejdspakke F) til at konvertere størrelsesfordelingen af torsk i IBTS og OSKAR togter til størrelsessammensætningen i havet.

Oskar togter (arbejdspakke D)

I hvert af årets fire kvartaler gennemførtes et moniteringstogt med to trawlere og en garnbåd med det formål at indhente information om den geografiske og sæsonmæssige fordeling af fangstrater og -sammensætning i Skagerrak og desuden at relatere disse variable til bl.a. dybde og temperatur. Størrelsesopdelte fangstrater for de enkelte målarter indgår desuden som input til GeoPop modellen (arbejdspakke F) samt til identifikation af eventuelle problematiske områder med mange ungfisk.

Forskerne: Moniterings- og procesbaseret viden (arbejdspakke E)

Skagerrak indgår i to årlige, videnskabelige moniteringstogter, IBTS: International Bottom Trawl Survey, i henholdsvis 1. og 3. kvartal. Disse der har til formål at give et rekrutterings-indeks for de fem kommercielt vigtige torskefisk samt sild, brisling og makrel. Størrelsesopdelte fangstrater af torsk på trækbasis fra disse togter indgår også som input til GeoPoP modellen (arbejdspakke F).

Information om størrelsesfordelinger fra de videnskabelige moniteringer foretaget under de såkaldte discard togter blev brugt til sammen med OSKAR togt data at give et billede af den geografiske fordeling af størrelsesfordelingen af torskefisk i fangsten med henblik på identifikation af eventuelle problematiske områder med mange ungfisk.

En række biologiske processer har enten direkte betydning for fiskenes geografiske fordeling eller kan bruges til at drage slutninger om dynamikken i fordelingerne. En viden om disse processer vil muliggøre mere valide og langsigtede forudsigelser. I projektet fokuserede vi på tre forskningsområder for torsk:

Genetiske analyser og bestandsstruktur (arbejdspakke E1)

En viden om mere eller mindre adskilte bestande af torsk og deres indbyrdes fordelingsdynamik vil muliggøre fiskeriforvaltning af bestande i stedet for områder og herunder tilrettelægge målrettede fiskerier efter specifikke bestandskomponenter. Det er derfor interessant at undersøge hvilke bestandskomponenter der bidrager til rekruttering af torsk i Skagerrak. I denne sammenhæng sammenlignedes den genetiske sammensætning hos gydetorsk fra to områder i den vestlige del af Skagerrak på grænsen til Nordsøen, der potentielt kunne bidrage til rekrutteringen.

Torskelarvernes vej med vandstrømmene frem til bundfældningsområderne (arbejdspakke E2)

En individbaseret model for spredningen af torskeæg og -larver, koblet til en fysisk-oceanografisk model og en sandsynlighedsfunktion for hvor torsken gyder, blev udviklet og testet i Nordsøen/Skagerrak. Modellen brugtes til at simulere (1) den tidsmæssige og geografiske fordelingsdynamik af torskelarver larver frem til bundfældning i Skagerrak, og (2) hvilke gydeområder (og gydebestande jf. arbejdspakke E1), der bidrager til rekruttering af torsk til Skagerrak.

Vækstdynamikken hos de juvenile torsk (arbejdspakke E3)

Væksthastighederne hos juvenile torsk fra tre områder af Skagerrak blev sammenlignet, da en forskellig vækst dels ville kunne sige noget om områdernes egnethed som habitat for torskene og dels ville give indikationer om hvor stedbundne torskene er, efter de har bundfældet sig.

Geostatistisk populationsmodel (GeoPop) (arbejdspakke F)

Der er brug for et værktøj som kan transformere togt data og andre fangstdata om til et billede af populationens rumlige fordeling i havet på et vilkårligt tidspunkt, og sådan at det bliver muligt at foretage statistiske tests af i hvor høj grad forskellige variable som f.eks. temperatur og dybde har betydning for en mere præcis beskrivelse af populationens fordeling på ethvert tidspunkt. Et sådant værktøj kaldet GeoPop modellen (geostatistisk populationsmodel) er blevet udviklet under Oskar projektet i forlængelse af et ph.d. projekt (Kristensen, 2008).

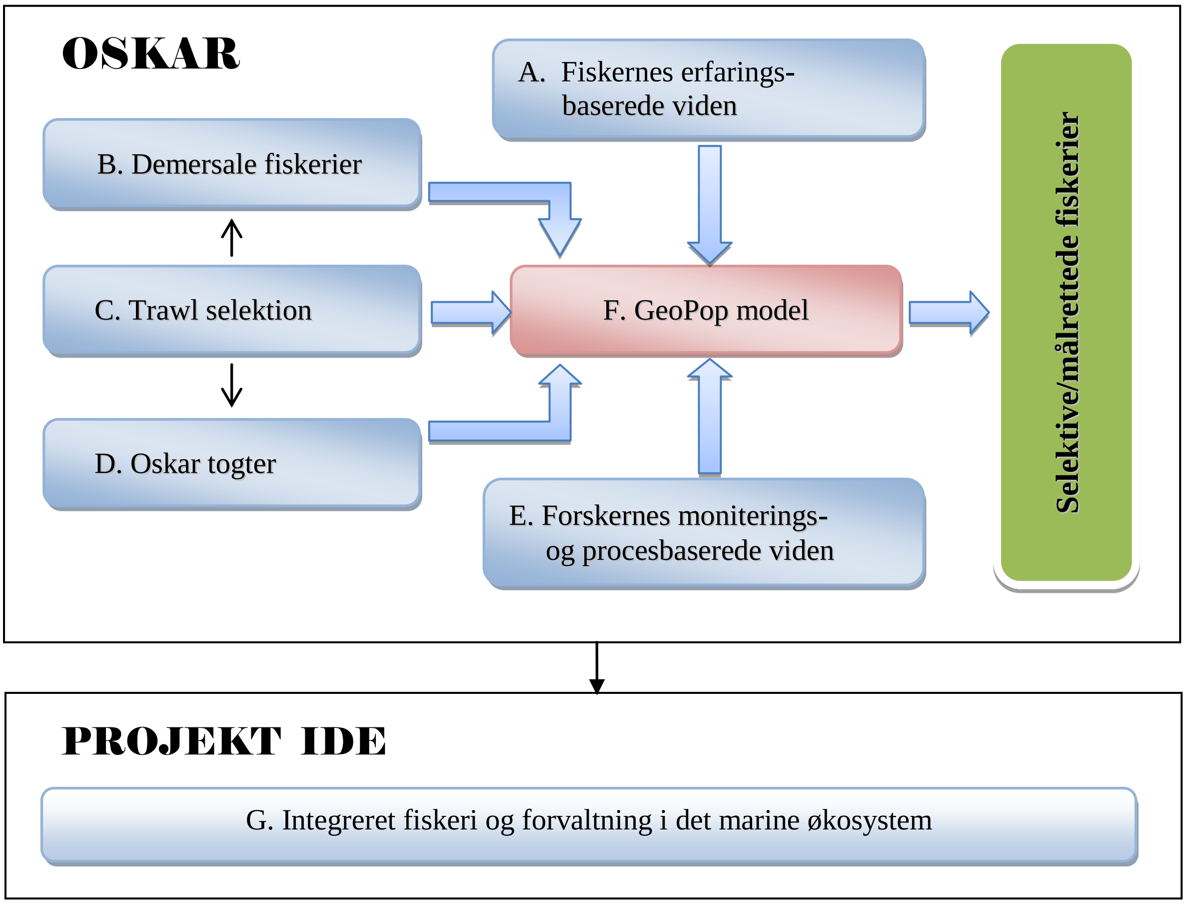
Ideen er at længde-frekvensdata fra de enkelte trawltræk i Oskar, IBTS, REX m.m. bruges til at beskrive det bjerglandskab som forekomsten eller fordelingen af små og store torsk kan siges at udgøre på ethvert tidspunkt i havet. Det er vigtigt at indse at man med denne metode også får fordelingsbilleder på tidspunkter og steder hvor der ikke er foretaget trawltræk. Med IBTS- og Oskar togt data estimeres modellens parametre for torsk inkl. selektionskurverne for trawlene i hvert af de to togter. GeoPop modellen tager også hensyn til variationen på lille skala, dvs. at to træk som er taget lige efter hinanden på nabostationer med præcis samme redskab og metode kan vise meget forskellige størrelsesfordelinger i fangsten af torsk. Det betyder at det vil være muligt at undersøge et nøglespørgsmål i Oskar nemlig om det har mening at foretage RTC på basis af fangsten i et enkelt trawl træk.

Integreret fiskeri og forvaltning i det marine økosystem (arbejdspakke G)

Som projekt ide samler arbejdspakke G alle Oskar tråde i et forslag til oprettelse af et Marint Datacenter, hvor data kan anvendes til at forbedre bestandsanalyser og prognoser, selektive redskaber samt til udarbejdelse af fiskeriudsigter på såvel kort som lang sigt (fra dage til år) med det formål at gøre fiskerne bedre i stand til at planlægge og optimere økologiske og økonomiske bæredygtige fiskerier.

Hoved ideen er at udnytte kommercielle fiskerioperationer til en omfattende indsamling af data om økosystemets øjeblikkelige tilstand. Omkostningerne vil være marginale da for eksempel fangstrapportering på trækniveau alligevel skal foretages i forbindelse med implementering af fuldt dokumenteret fiskeri. Som grundlag for et moderne sensorbaseret fiskeri skal fiskerne endvidere udstyres med videnskabeligt måleudstyr.

Det forventes at integreret fiskeri og forvaltning i det marine økosystem kan udvikles ved kombination af sensorbaseret fiskeri, fangstkvote forvaltning, Oskar, økosystem forvaltning og videnskabelige surveys.

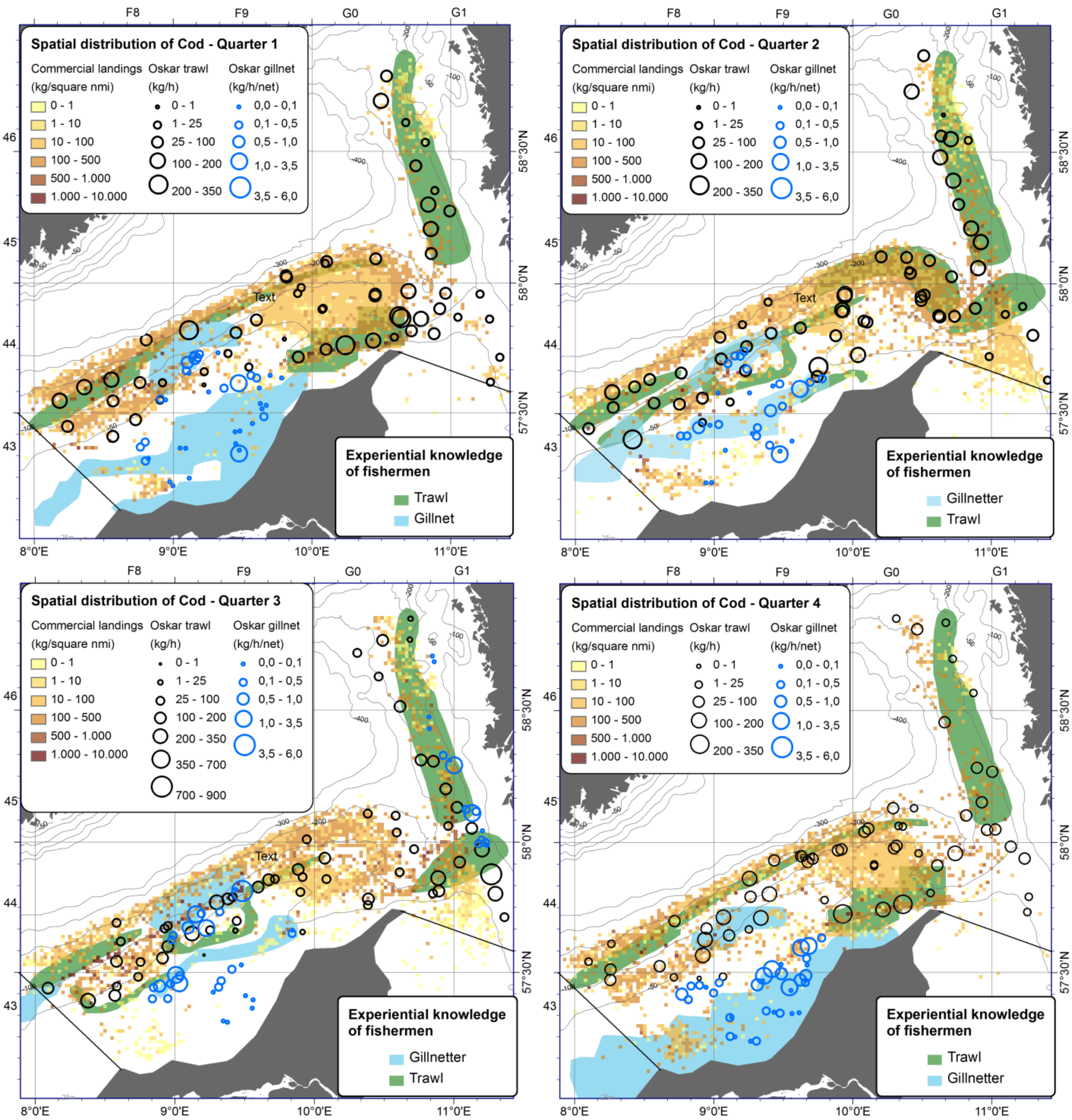


Figur 1. Arbejdspakkerne og deres indbyrdes sammenhænge.

Resultater og diskussion

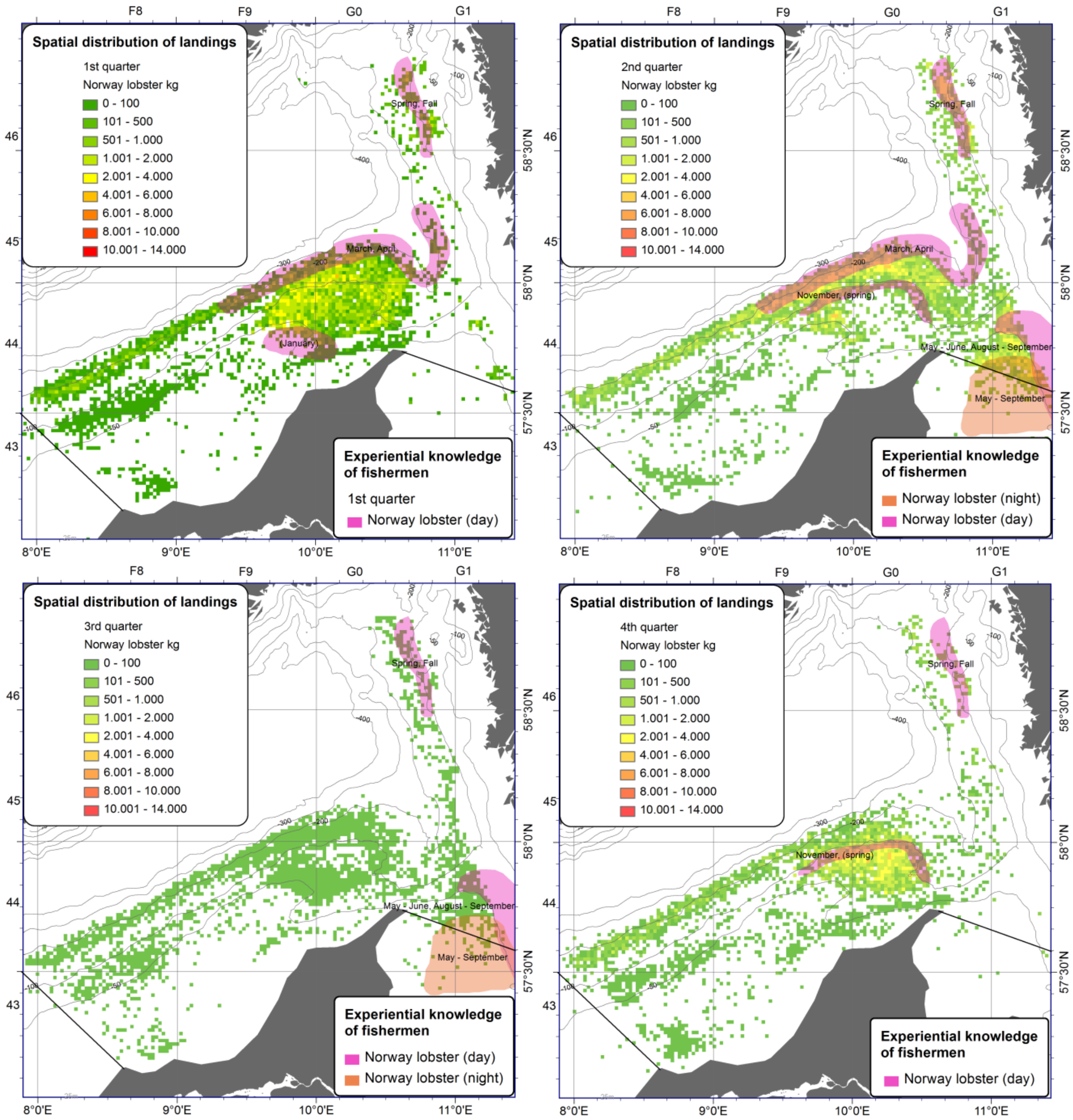
I Figur 2(a)-(d) sammenlignes trawl- og garnfiskernes erfaringsbaserede viden om den geografiske fordeling over året med fordelingen af de kommercielle landinger (fartøjer >15 m) og Oskar-fiskernes fangstrater af de fire vigtigste målarter, torsk, jomfruhummer, sej og rødspætte.

I de store træk ser det ud til at fordelingen af de kommercielle landinger stemmer godt overens med fiskernes erfaringer for hvor disse arter befinder sig gennem de fire sæsoner. Specielt når man tager i betragtning at det primært er jomfruhummerfiskeriet der styrer effortfordelingen.



Figur 2(a). Trawl- og garnfiskernes erfaringsbaserede viden om **torskens** geografiske fordeling i Skagerrak (hhv. grønne og blå områder), opdelt i årets fire kvartaler og sammenlignet med de samlede landinger fra fartøjer >15 m i 2008-2010 (farvede 1x1 sømil kvadrater) samt trawlernes og garnbådens fangstrater på trækbasis under Oskar togterne (henholdsvis sorte og blå cirkler).

Afvigelser som f.eks. torsk på lavt vand i 4. kvartal i Jammerbugten [Figur 2(a)], hvor de store garnfangster i OSKAR togtet ligger i yderkanten af det af garnfiskerens angivne område, kan forklares ved fiskene endnu ikke er trukket helt ind under land. Dette sker først i slutningen af kvartalet. De store kommercielle landinger af torsk nord for Skagen uden for områderne angivet af trawlfiskerne skyldes desuden den store effort, der allokeres til fangst af jomfruhummer i dette område.

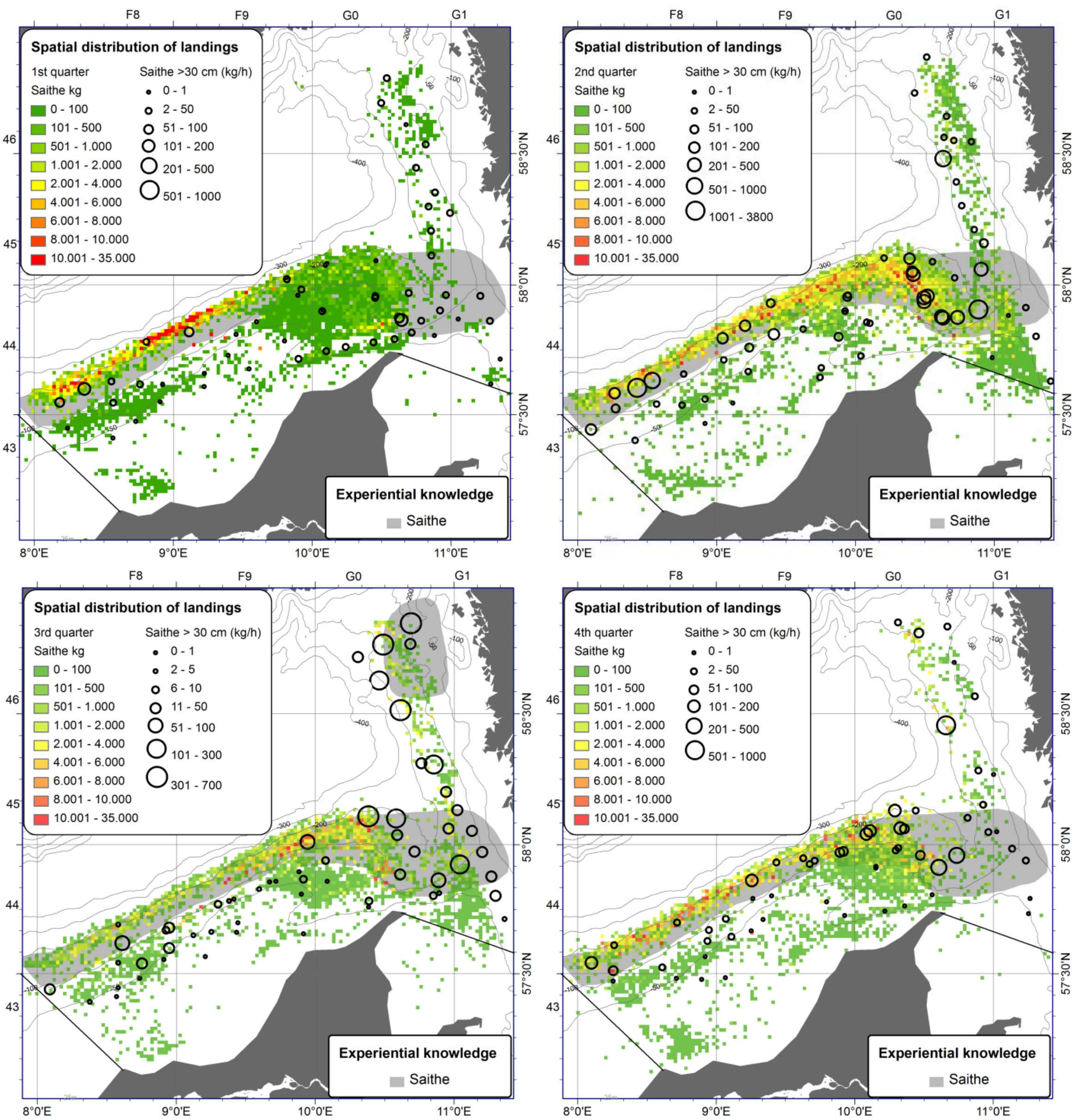


Figur 2(b). Trawlfiskernes erfaringsbaserede viden om **jomfruhummerens** geografiske fordeling i Skagerrak (pink og orange områder), opdelt i årets fire kvartaler og sammenlignet med de samlede landinger fra fartøjer >15 m i 2008-2010 (farvede 1x1 sømil kvadrater).

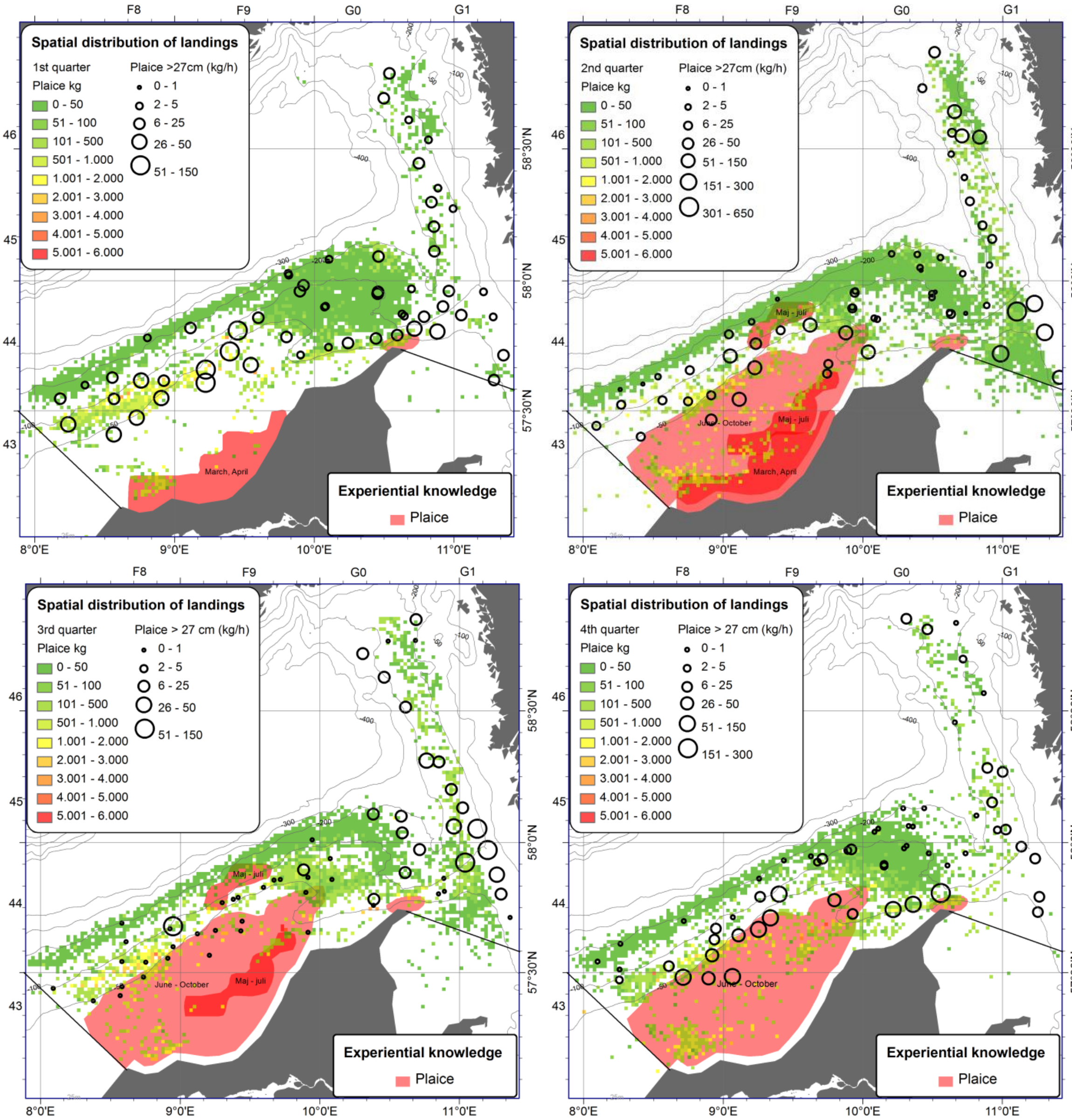
For jomfruhummerens vedkommende ser det ud til at fordelingen af landinger strækker sig væsentlig længere mod vest end angivet af fiskerne, samt at der i 3. kvartal fanges væsentlige mængder af hummer i området nord for Hirtshals og Skagen, mens fiskerne ikke har angivet dette område.

Der er god overensstemmelse mellem fiskernes erfaringsbaserede viden om mørksej og både de totale kommercielle landinger og trawlfangsterne fra Oskar projektet.

Rødspætten er en art for hvilken fordelingen af landingerne ikke er styret af fiskeriet efter jomfruhummer. Dette fremgår tydeligt af Figur 2(d), hvor det ses at de væsentlige landinger hidrører fra lavere vanddybde.

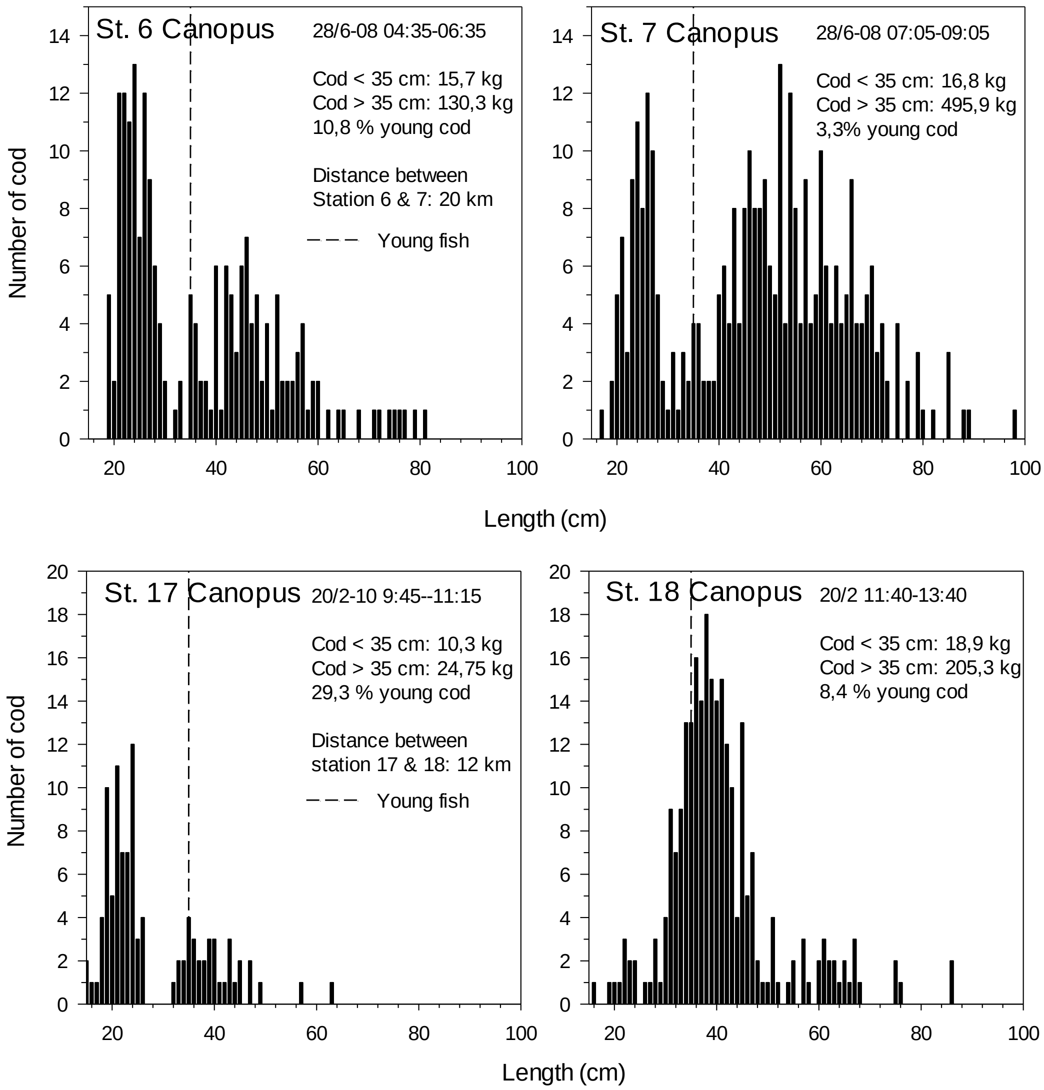


Figur 2(c). Trawl- og garnfiskernes erfaringsbaserede viden om **sejens** geografiske fordeling i Skagerrak (farvede områder), opdelt i årets fire kvartaler og sammenlignet med de samlede landinger fra fartøjer >15 m i 2008-2010 (farvede 1x1 sømil kvadrater) samt trawlernes fangstrater på trækbasis under Oskar togterne (sorte cirkler).



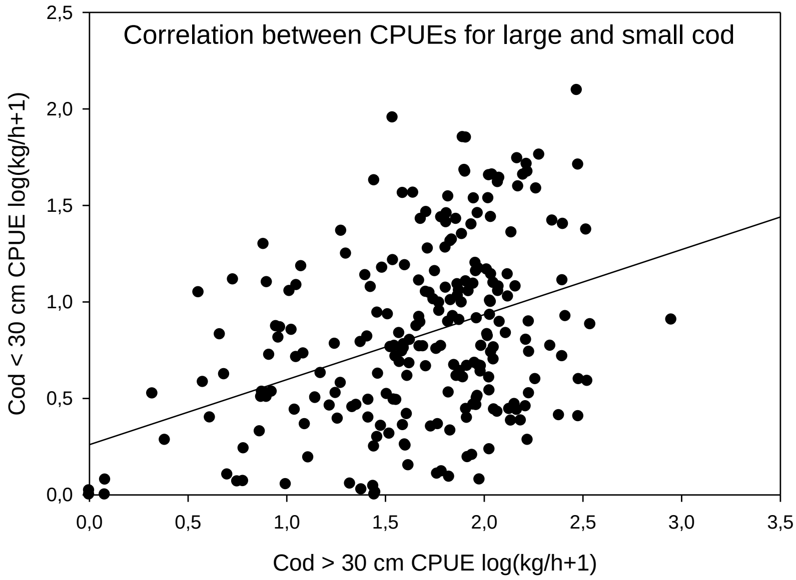
Figur 2(d). Trawl- og garnfiskernes erfaringsbaserede viden om **rødspættens** geografiske fordeling i Skagerrak (farvede områder), opdelt i årets fire kvartaler og sammenlignet med de samlede landinger fra fartøjer >15 m i 2008-2010 (farvede 1x1 sømil kvadrater) samt trawlernes fangstrater på trækbasis under Oskar togterne (sorte cirkler).

I Figur 3 illustreres variationerne i størrelsesfordelingen af torsk i fangster fra nabotræk. Størrelsesfordelingerne er markant forskellige, og således er også andelene af ungfisk i forhold til den samlede fangst af torsk. Dette indikerer at det vil være vanskeligt eller umuligt på grundlag af størrelsesfordelingen i enkelt-træk at vælge et område frem for et andet på med henblik på at undgå for store bifangster af ungfisk.



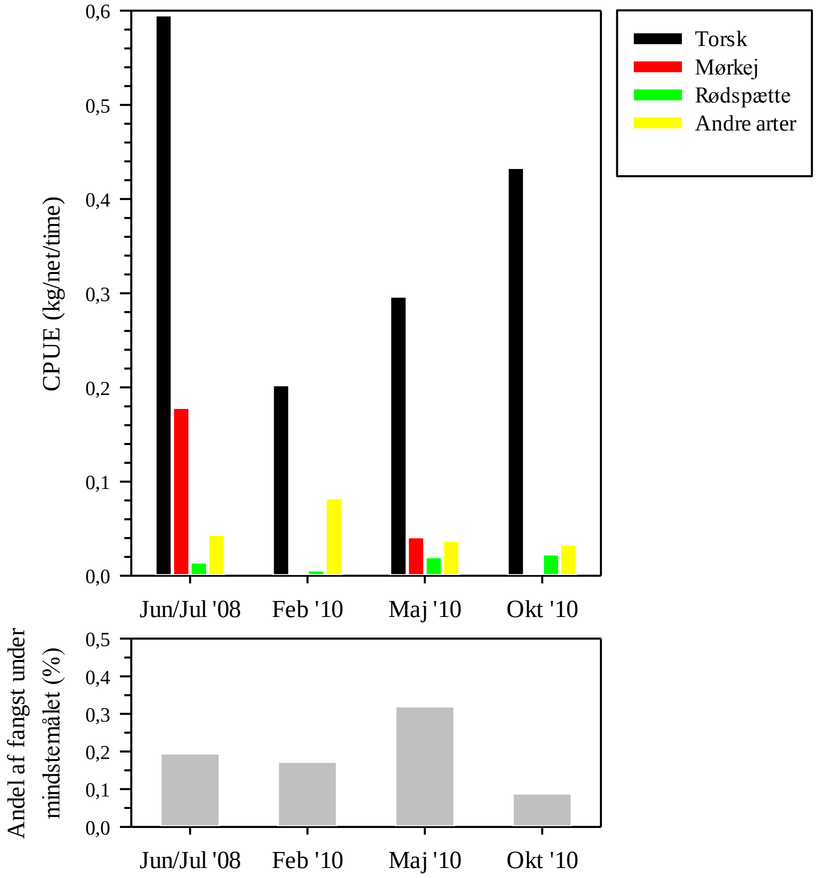
Figur 3. Længde frekvens fordeling af torsk i fangsten hos trawleren *Canopus* på de to nabo-stationer 6 og 7 under 3. kvartalstogtet i 2008 (øverst) og de to nabo-stationer 17 og 18 under 1. kvartalstogtet i 2010 (nederst). Desuden er angivet vægtprocenten af ungtorsk i forhold til samlet fangst af torsk.

Analyser af trawldata fra Oskar antyder at store landinger generelt *ikke* betyder høje fangstrater af undermålsfisk (arbejdspakke D). Kun hos torsk er der en signifikant positiv korrelation mellem fangstrater af hhv. undermålsfisk og fisk over målet (Figur 4). Dette kunne indikere at fiskeren, der går målrettet efter torsk har et problem med bifangst af ungfisk med mindre redskabet er tilstrækkeligt selektivt. Men derudover kan man sige at man i såvel det blandede trawlfiskeri som det målrettede trawlfiskeri efter mørksej og jomfru-hummer i Skagerrak har muligheden for ved valg af passende områder og tidspunkter på året at optimere fangsten uden nødvendigvis at forøge uønsket bifangst af undermålsfisk af de kommercielt vigtigste arter.



Figur 4. Fangstrater af undermålstorsk plottet mod fangstrater af torsk over målet. Trawler-data fra alle Oskar togter samlet. Der er en signifikant positiv korrelation (hældning=0.34; *P*<0.005).

På alle Oskar-togter med garnbåden udgjorde torsk størstedelen af fangsten af konsumarter (Figur 5). Desuden indgik mørksej og rødspætte over mindstemålet i fangsterne i henholdsvis to og fire togter, og herudover også enkelte kuller. Hvilling var ikke med i fangsten. Andre arter omfatter lyssej og rødtunge. Bifangst af undermålsfisk af kommercielle arter var meget små med en maksimal værdi på mindre end 0.4 % i maj 2010.



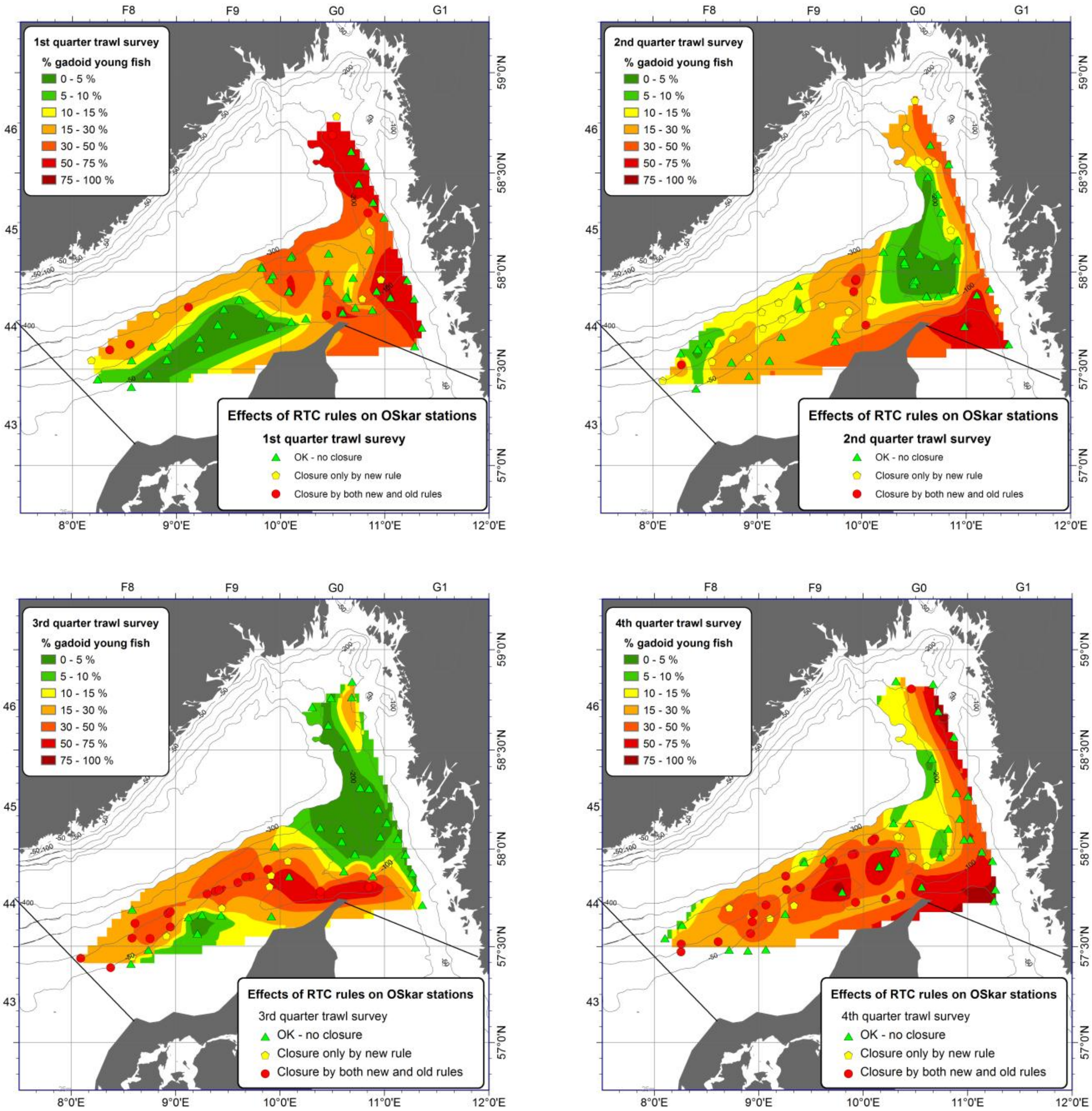
Figur 5. Garnbådens fangst af kommercielle arter over mindstemålet (øverst) og andel samlet bifangst af kommercielle arter under mindstemålet (nederst).

Vægtandelen af ungfisk i forhold til trawlernes samlede fangst af torsk, hvilling, kuller og sej for hvert træk under Oskar togterne kan give et fingerpeg om hvilke og hvor store områder, der kan være problematiske hvis man skal undgå Real Time Closures (RTC). Det er kun et fingerpeg, fordi Oskar forsøgsfiskeriet i modsætningen til det kommercielle fiskeri var målrettet mod torsk og med stort vertikalt gab i trawlene. Det er derfor ikke mærkeligt at de Oskar baserede kort i Figur 6(a) viser langt større røde områder end de discard baserede kort i Figur 6(b) for stor andel af ungfisk i fangsterne. Resultaterne i Figur 6 viser at store områder kunne give problematisk høje andele af ungfisk, men kun få træk med fangster, der er så store at de opfylder alle betingelser for at iværksætte en RTC (arbejdspakke D), ville medføre dette. Når fangsten omregnes til hvad der vil tilbageholdes i et standardtrawl med 120 mm løft mindskes arealet af de problematiske områders betydeligt og de grønne områder udgør den største andel af forsøgsarealet bortset fra 4. kvartal (Figurerne 39-42 i arbejdspakke D).

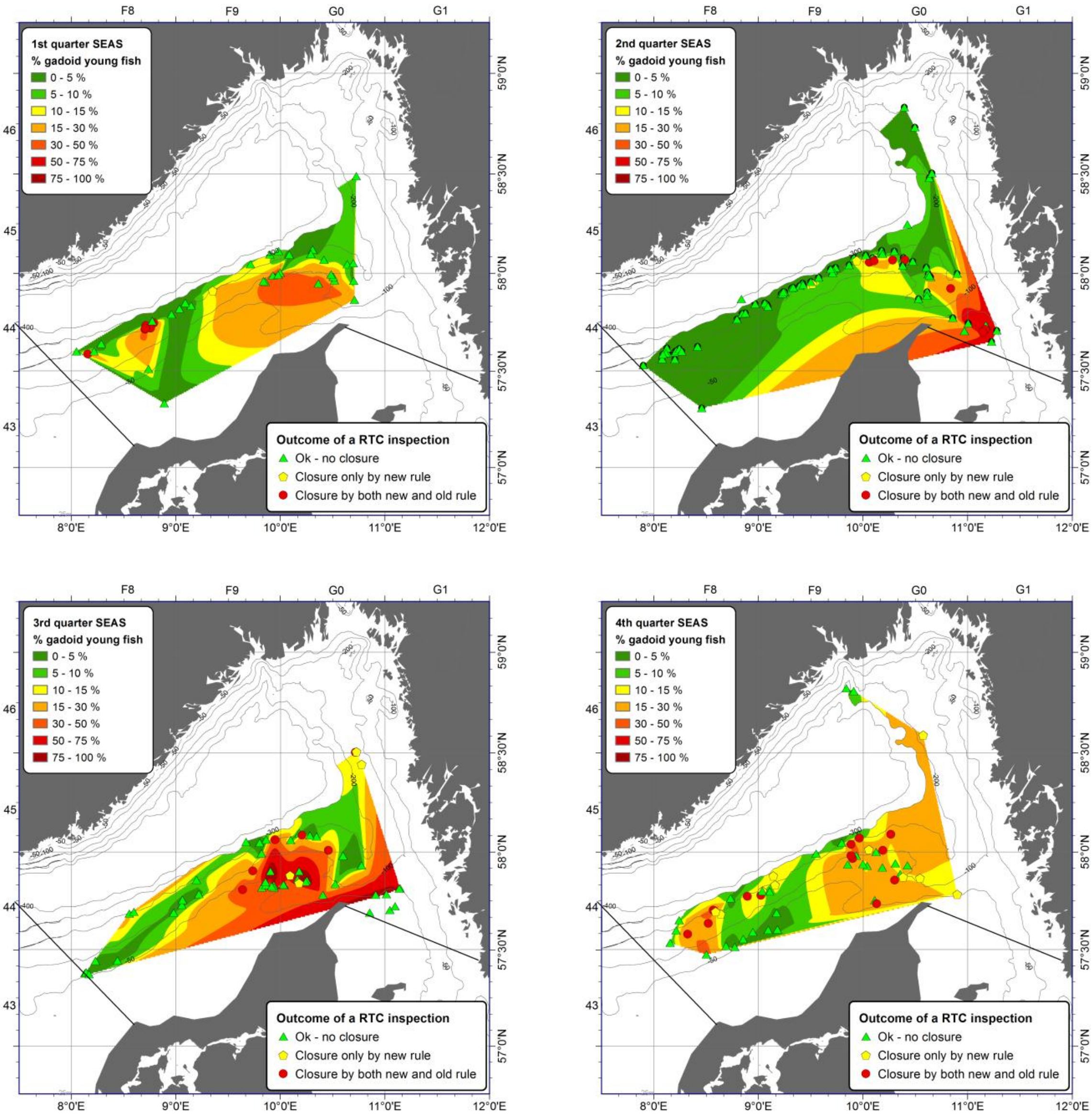
Hurtig guide til fortolkning af kortene i fig. 6: Grøn trekant i grønt område betyder <10 % ungfisk i fangsterne af torskefisk. Grøn trekant i orange eller røde områder betyder fangster <200 kg men >15 % ungfisk i fangsterne i området; forøget træktid kunne potentielt give et problem. Gule punkter i gule, orange eller røde områder betyder fangster mellem 200 kg og 300 kg og >10 %

ungfisk i fangsterne i området. Røde punkter i orange eller røde områder betyder fangster >300 kg og mere >15 % ungfisk i fangsterne i området.

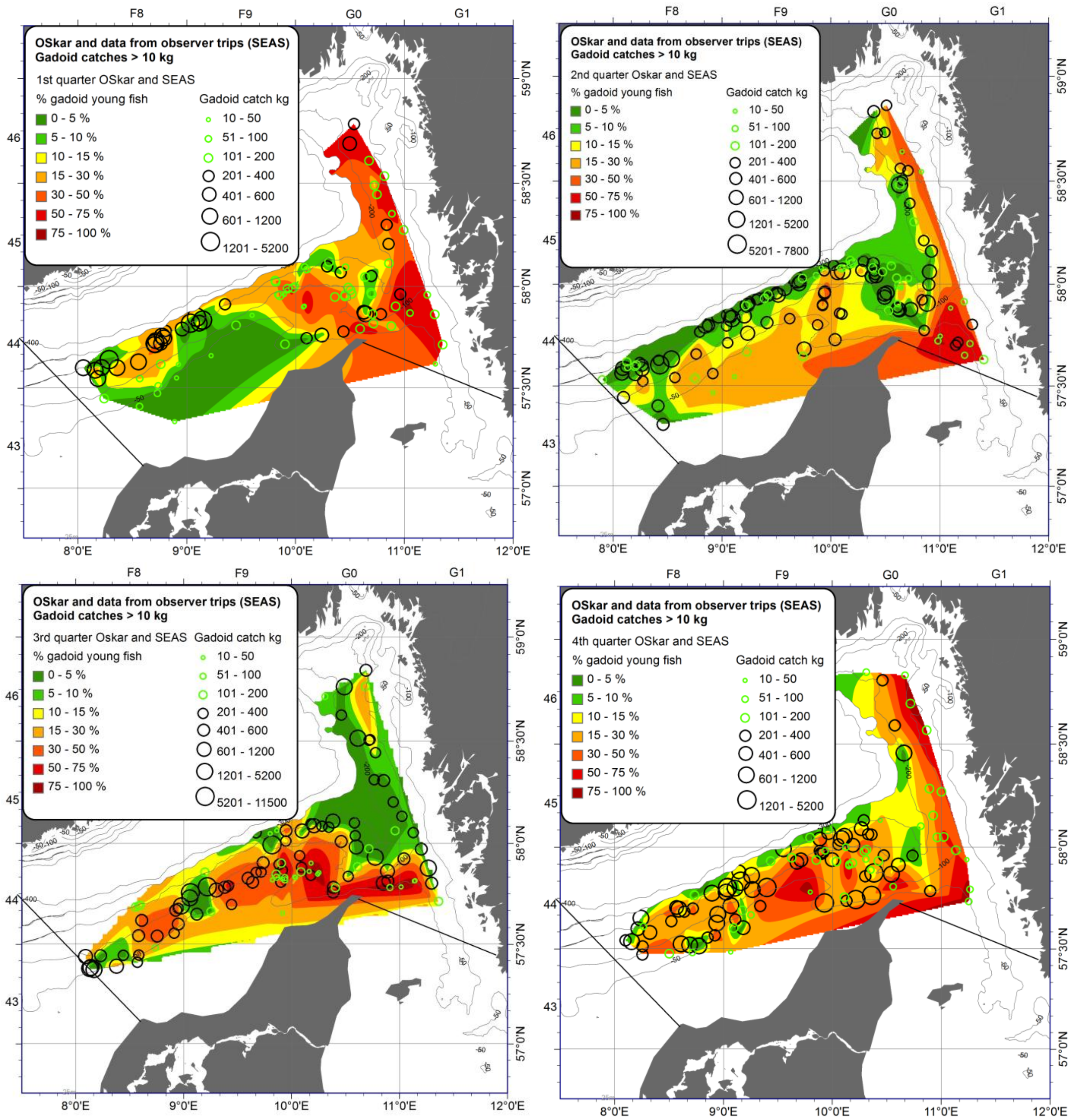
Det er vigtigt at bemærke at kortene viser betydelige forskelle på kvartalsbasis. For eksempel er afgrænsningen af Oskar fangstområdet i 1. og 4. kvartal 2010 [Figur 6(a)] mod nord-øst udpræget rød i modsætning til gennemsnittene for fangster på discard turene i de tilsvarende kvartaler for 2008-2010 [Figur 2(b)] på trods af 2-4 gange længere træktider. Det er sådanne forskelle og variationer i fangstsammensætninger over større områder samt i fangsterne mellem nabotræk (Figur 3) der indikerer at for eksempel RTC-kriterier for ungfisk populationen i havet bør fastsættes baseret på et solidt real time datamateriale og et værktøj, der kan oversætte lokal fangstrater til viden om den lokale tæthed af ungfisk (jf. GeoPop modellen). Af disse årsager skal det samlede fordelingskort i Figur 6(c) fortolkes med varsomhed.



Figur 6(a). Andelen (% vægt) af ungfisk af arterne torsk, hvilling, kuller og sej i forhold til den samlede fangst af disse torskefisk på trækbasis for de to trawlere under **Oskar togterne** i hvert af årets fire kvartaler. De farvelagte områder er interpolationer (natural neighbour) i GIS af de observerede værdier i trawltræk med mere end 10 kg torskefisk i fangsten. ▲ angiver træk, der ikke ville forårsage en realtime closure (RTC); ● angiver træk, der ville forårsage en RTC efter de nye (13/8-2011) regler (total fangst af torskefisk >200 kg og andel af ungfisk >10 %); ● angiver træk, der ville forårsage en RTC efter såvel de nye som de gamle regler (total fangst af torskefisk >300 kg og andel af ungfisk >15 %).



Figur 6(b). Andelen (% vægt) af ungfisk af arterne torsk, hvilling, kuller og sej i forhold til den samlede fangst af disse torskefisk på trækbasis for alle OTT og OTB trawlere med maskestørrelse mellem 90 mm og 120 mm under **discard togterne** i hvert af årets fire kvartaler i 2008-2010. De farvelagte områder er interpolationer (natural neighbour) i GIS af de observerede værdier i trawltræk med mere end 10 kg torskefisk i fangsten. ▲ angiver træk, der ikke ville forårsage en realtime closure (RTC); ● angiver træk, der ville forårsage en RTC efter de nye (13/8-2011) regler (total fangst af torskefisk >200 kg og andel af ungfisk >10 %); ● angiver træk, der ville forårsage en RTC efter såvel de nye som de gamle regler (total fangst af torskefisk >300 kg og andel af ungfisk >15 %).



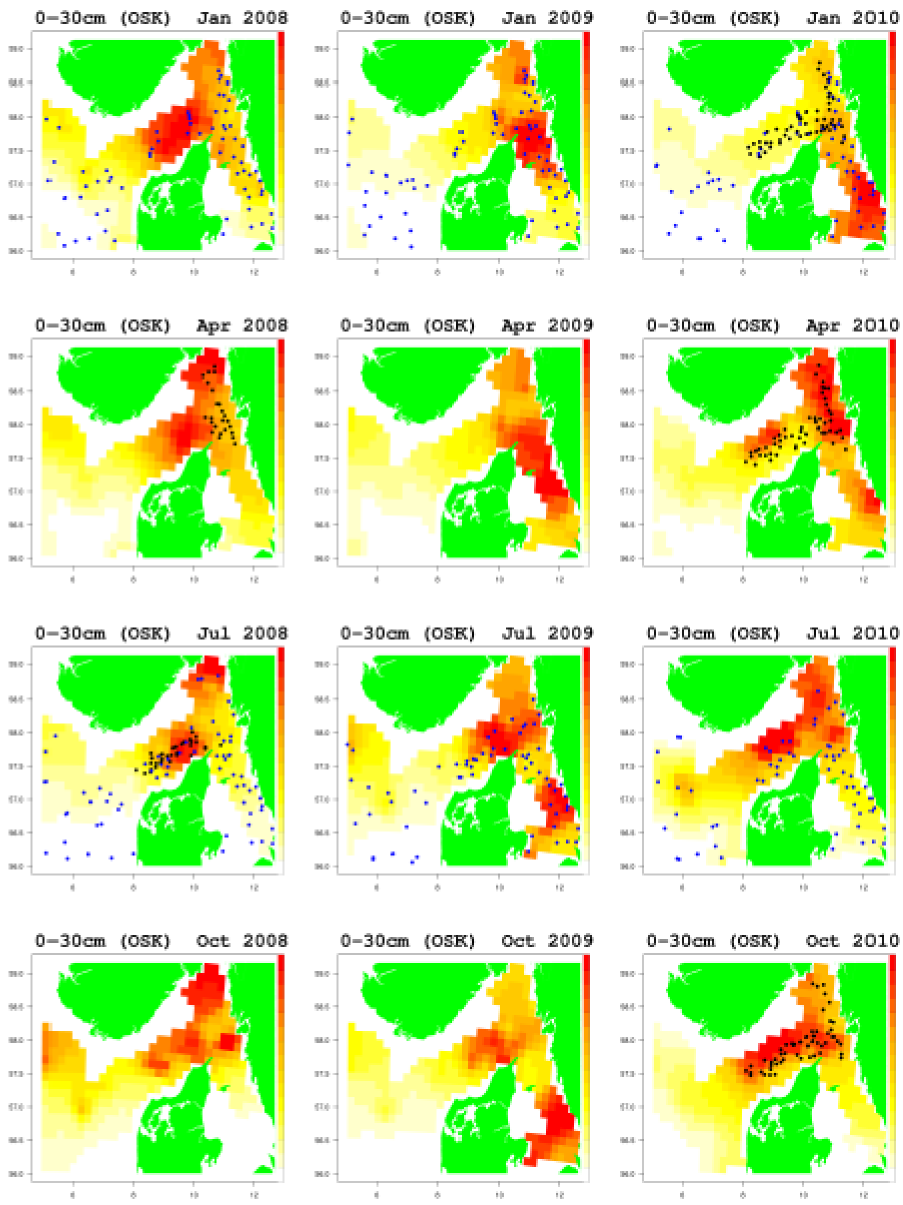
Figur 6(c). Andelen (% vægt) af ungfisk af arterne torsk, hvilling, kuller og sej i forhold til den samlede fangst af disse torskefisk på trækbasis for **Oskar og discard togter samlet** i hvert af årets fire kvartaler [se Figur 6(a) og 6(b)]. De farvelagte områder er interpolationer (natural neighbour) i GIS af de observerede værdier i trawltræk med mere end 10 kg torskefisk i fangsten. Fangster under 200 kg er markeret med grønne cirkler for at angive at farven på disse områder er baseret på relativt små fangster af torskefisk.

Resultatet af den geostatistiske populationsmodel GeoPop er en film, som på ugebasis viser udbredelsen af en given størrelsesgruppe af torsk f.eks. op til 30 cm, dvs. den relative fordeling i Skagerrak af ungtorsk som endnu ikke er kønsmodne. Billederne på Figur 7 viser resultatet baseret på Oskar togt data i den første uge i hvert kvartal gennem hele Oskar perioden 2008-2010. Inkludering af IBTS data ændrer ikke billedet generelt for størrelsesgrupperne (arbejdspakke F), hvilket indikerer at modellen som sådan er konsistent. Der er nogle uoverensstemmelser i juni-juli 2008 og maj 2010, men her er der ikke noget tidsmæssigt overlap mellem Oskar og IBTS træk. Forskellen skyldes en forøget præcision pga. den forbedrede tidsmæssige dækning ved brug af begge datasæt. Måneder hvor både OSKAR og IBTS træk indgår, viser bemærkelsesværdig ens billeder af udbredelsen af de forskellige størrelsesgrupper.

Det er netop disse forhold der betyder at vi kan have tillid til modellen og dens resultater. Hvis det ikke var tilfældet ville det være nødvendigt at udbygge modellen med hypoteser om årsagerne til for eksempel forskellige fangbarheder (catchabilities) for store torsk mellem GOV-trawlet i IBTS og Oskar trawlet. Vi forventer at denne problemstilling bliver aktuel for Nordsø torsken fordi forskellen mellem IBTS fangstrater på glat bund og (REX/RESOURCE) fangstrater af store torsk på den hårde bund her er mere udpræget. Det skal her bl.a. undersøges og testes videnskabeligt om trawleffektiviteten (gear efficiency) i IBTS falder for de store torsk – et forhold der ikke er medtaget i Oskar. Samtidig er der kun 1-2 IBTS træk pr. ICES rektangel i Nordsøen i forhold til betydelig flere IBTS træk pr. rektangel i Skagerrak og specielt i Kattegat. Disse spørgsmål ligger udenfor rammerne af Oskar projektet, men vil blive taget op i afslutningen af søsterprojektet RESOURCE i 2012 der i forlængelse af REX-projekterne også fokuserer på bestandsvurdering.

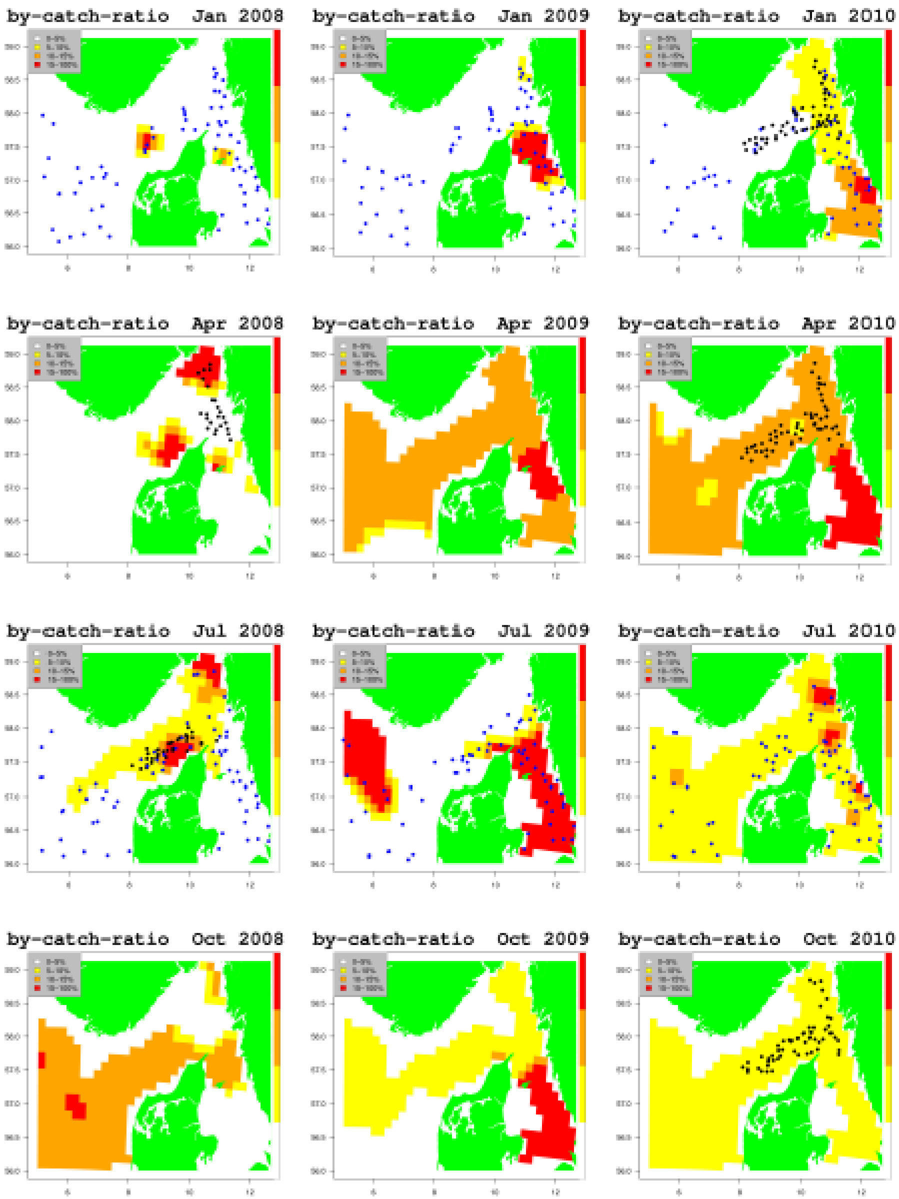
Imidlertid er det vigtigste resultat af GeoPop modellen i dette studie nok effekten af den dominerende variabilitet på lille geografisk skala, som blev illustreret ved forskellene i størrelsesfordeling fra nabo-træk i Figur 3. Konsekvensen af dette er meget klar, når man sammenligner kortene med den forventede bifangst. Figur 8 indikerer at det er muligt at kontrollere den totale bifangst af en flåde ved en planlagt geografisk allokering af fiskeri-efforten: Hvis de røde områder undgås, vil den samlede bifangst være under 15 %. Derimod er det ifølge Figur 9 umuligt at opnå en lignende kontrol for det enkelte træk – uanset hvor trækket tages, vil der altid være en signifikant risiko for at få en for stor bifangst.

Områdespecifik populationsstruktur, rekruttering, vækst, dødelighed og migration er nødvendige størrelser at have styr på hvis man skal forstå baggrunden for dynamikken i fordelingerne af de forskellige størrelsesgrupper og dermed videreudvikle en model, der bare en sæson eller et år frem i tiden med rimelig sikkerhed kan forudsige fordelingsdynamikken. I Oskar projektet indledtes nogle studier af rekruttering og vækst, der illustrerer nytten af en sådan procesviden. De genetiske studier (arbejdspakke E1) viste således at gydepopulationen ved kanten af Norske Rende fra den vestlige del af grænsen mellem Skagerrak og Nordsøen og op langs syd-vestkysten af Norge er genetisk forskellig fra gydefisk på den danske side, der til gengæld ikke er forskellige fra andre prøver i Nordsøen. Dette kan forklares ud fra modelstudiet (arbejdspakke E2) af vandstrømmenes transport af torskelarver fra gydefelterne og frem til de områder, hvor torskene bundfælder. Af dette studie fremgår det nemlig at pulserne af larver ind i Skagerrak kommer fra vest og syd, mens larverne ved Norske rende transporteres nordover og således tilsyneladende ikke bidrager til rekrutteringen i Skagerrak. Det fremgår desuden at torskelarver fra de andre områder af Nordsøen i alle de simulerede år (2004-2008) aggregerer i Skagerrak, og at aggregationsmønsteret varierer fra år til år afspejlende forskellen i havstrømmenes dynamik mellem årene. Endelig viser undersøgelsen af vækstdynamikken hos torsk (arbejdspakke E3) at tilvæksten hos de bundfældede, unge torsk i forskellige områder af Skagerrak varier systematisk frem til torskene er omkring 35 cm lange. Dette indikerer at de unge torsk er relativt stedbundne og ikke vandrer rundt i Skagerrak. Hvis disse resultater holder, burde man kunne forudsige fordelingen af unge torsk et par år ud i fremtiden allerede når man kender aggregations-mønsteret for de juvenile torsk i den periode hvor de søger mod bunden.



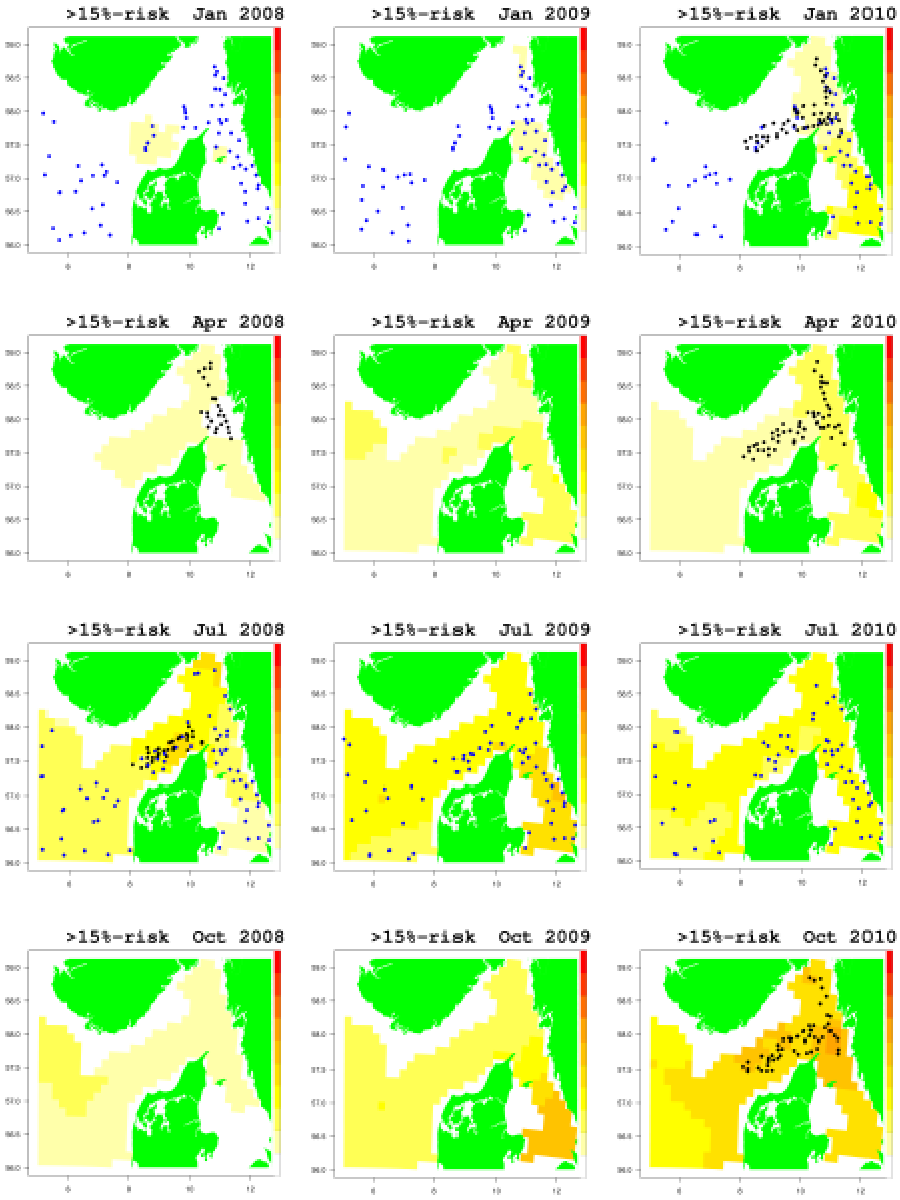
Figur 7. GeoPop modellens forudsigelser af den geografiske fordeling i havet af torsk op til 30 cm.

Den videnskabelige viden f.eks. fra IBTS, er ikke udnyttet sammen med fiskernes oplysninger i nogen tidligere analyser af arts- og størrelsesfordelingsdynamik i Skagerrak. Det betyder samlet at Oskar og lignende problemstillinger ikke kan løses med mindre alle erfaringerne udnyttes og systematiseres på en sådan måde at viden om den geografiske fordeling af torsk kan uddrages og kvantificeres. Det er vigtigt at erkende at i RTC sammenhænge bør det være den geografiske fordeling af populationen i havet som udgør den afgørende faktor. Det er også vigtigt at såvel fiskere som forskere og forvaltere erkender at de virkelige populationsforhold er forskellige fra det rumlige eksplicitte billede fiskerne og forskerne direkte ser igennem fangstsammensætning. Der skal et nyt værktøj til så disse populationsforhold kan uddrages og usikkerhederne kvantificeres.



Figur 8. GeoPop modellens forudsigelse af den geografiske fordeling af den relative bifangst (procentvise andel af torsk under 30 cm i forhold til samlede vægt af torsk i fangsten) ved brug af OSKAR trawl. Hvis et stort antal træk tages uden for de røde områder vil den samlede fangst have en bifangst på mindre end 15 %.

GeoPop modellen er sådant et værktøj og resultaterne viser hvordan fordeling af torsk i Skagerrak ændrer sig gennem hele perioden 2008-2010 for en vilkårlig størrelse af torsk. Det er muligt i denne periode at finde områder og tidspunkter hvor de forskellige størrelsesklasser ikke overlapper hvilket potentielt åbner op for 'cod avoidance' strategier baseret på totalselektion (og ikke kun på selve redskabsselektionen). GeoPop modellen kan i sin nuværende første version ikke direkte bruges til at forudsige ændringer i torskens fordeling frem i tiden, men Oskar arbejdet viser hvordan det kan gøres i et evt. efterfølgende udviklingsprojekt. Oskar kan i sin nuværende udgave kun give relative resultater for bestanden, men arbejdet kan bruges til at specificere hvordan en up-to-date bestandsvurderingsmodel for hele havområdet kan bruges som udgangspunkt for en rumligt eksplicit model (GeoPop). Det bemærkes at alle gængse bestandsvurderings modeller i dag stadig opfatter fiskebestande som homogent fordelt i havet så en tilgang som den i GeoPop modellen er innovativ.



Figur 9. GeoPop modellens forudsigelse af den geografiske variation af risikoen for at fange mere end 15 % ved et træk med OSKAR trawl, når der tages hensyn til variationen i størrelsesfordeling på lille geografisk skala. Der er meget lille kontrast pga. den dominerende variabilitet på lille skala.

Når GeoPop filmen udelukkende på basis af Oskar og IBTS togt data viser hvordan den geografiske fordeling af en størrelsesklasse af torsk ændrer sig henover året så er det hverken simpelt at fortolke eller validere denne film. Det sidste forhold skyldes at vi har brugt alle tilgængelige togtdata til at lave filmen så der ikke findes tilgængelige og uafhængige data i dag udover fiskernes erfaringsbaserede viden til at teste modellen. Da estimeringen af parametrene i GeoPop modellen næsten er uafhængig af en trin for trin forøgelse af datamaterialet (fra IBTS til IBTS+OSKAR osv.), kan man som et første testskridt køre GeoPop modellen alene på IBTS data over en længere årrække og så benytte Oskar som testdata. Det er ikke gjort i nærværende projekt, fordi det også er nødvendigt at forholde sig til fortolkningen af fordelingsdynamikken. Når filmen viser at koncentrationen af en størrelsesgruppe af torsk flytter sig fra et område i Skagerrak til et andet i løbet af 2008, 2009 eller 2010 så kan det skyldes områdespecifikke forskelle i vækstrater, dødeligheder og/eller migrationer. Viden om disse forhold er ikke medtaget i den første version af GeoPop modellen, men de indledende studier af vækst og rekruttering af torsk viser at det er vigtigt med en bedre viden om disse processer i udviklingen et virkelig prædiktivt værktøj. Øget viden om områdespecifik populationsstruktur (genetik), rekrutteringspotentiale, fouragering og vækst samt gydemigrationer vil kunne inkorporeres i GeoPop modellen, som fremadrettet kan bruges til rådgivende scenarie-modeller til både på kort sigt ('Fiskerudsigt' de næste uger) og langt sigt (fiskeripotentiale de næste år) at komme med brugbare forudsigelser. Kravet hertil er også udbygning af datamateriale fra videnskabelige togter med trawl data på trækniveau i det kommercielle fiskeri hvor målinger af temperatur m.v. også indgår. Det er disse perspektiver, som en evaluering af Oskar lægger op til, og som udgør grundtanken i det forslag til udviklingsprojekt, der er skitseret nedenfor.

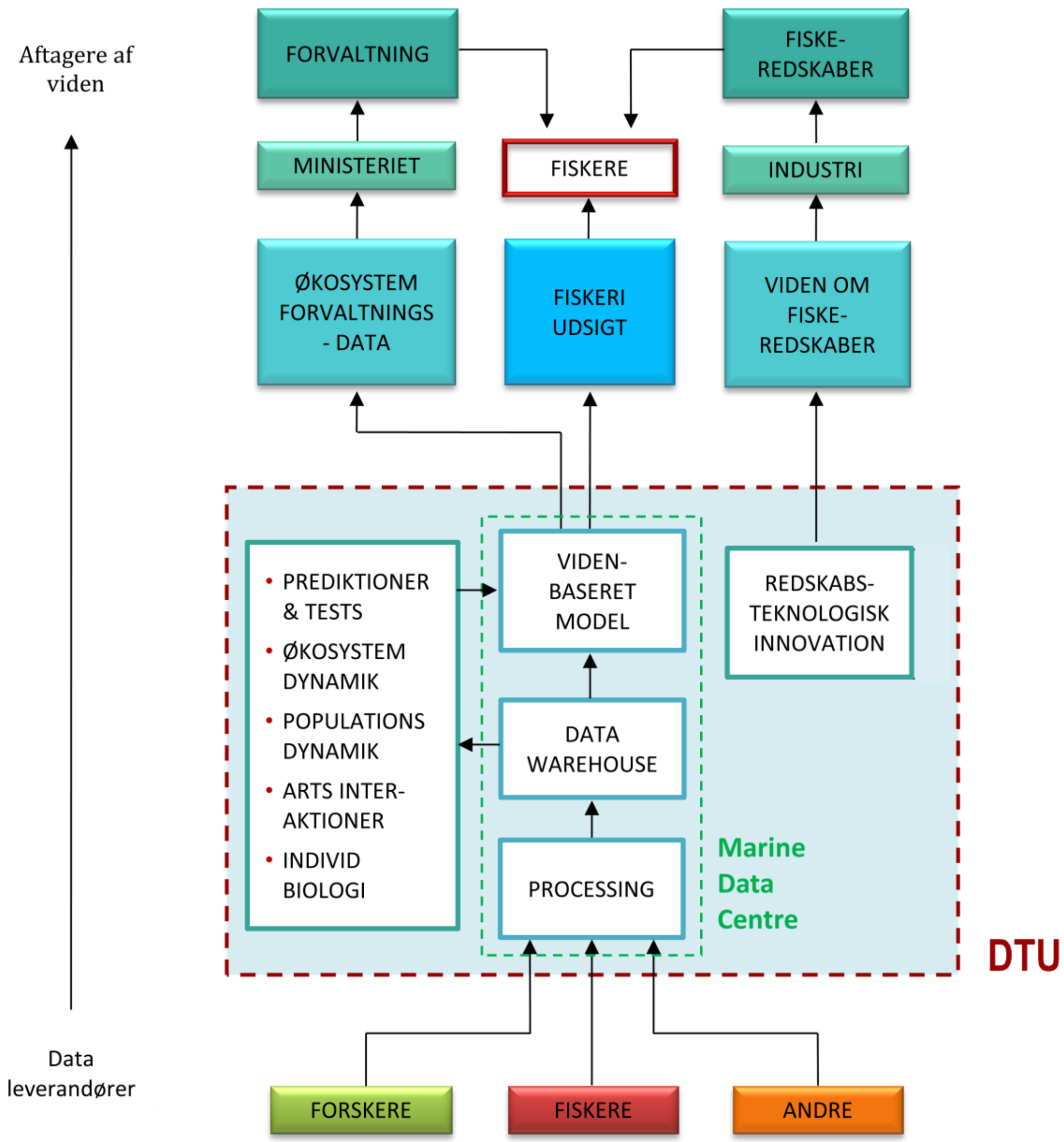
Forslag til udviklingsprojekt (arbejdspakke G): Integreret fiskeri og forvaltning af det marine økosystem

Aktiviteterne i dette nye måleprogram er illustreret med et dataflowdiagram i Figur 10. Data fra fiskere, forskere og andre kilder samles i et Marint Datacenter, hvor der indledningsvis foretages en oparbejdning, der sikrer datakvalitet og bringer data på et standardiseret format, der er velegnet til lagring og udveksling i et datawarehouse. Data anvendes til (1) eksisterende bestandsanalyser, (2) ny forskning i bl.a. adfærd af marine organismer, populationsdynamik, artsinteraktioner, og økosystemmodellering med henblik på forbedrede bestandsanalyser og -prognoser, og (3) udarbejdelse af fiskeriudsigter på såvel kort som langt sigt (fra dage til flere år) med formålet at gøre fiskerne bedre i stand til at planlægge og optimere deres fiskerier. Fiskeriudsigten kan desuden bruges til at validere datagrundlag og modeller, idet fiskerne direkte vil kunne konstatere om systemets prædiktioner er korrekte.

Den grundlæggende idé i dette projektforslag er at udnytte den kommercielle fiskerflåde til omfattende indsamling af data om den øjeblikkelige tilstand af det marine økosystem. Dataindsamlingen kan foretages som en integreret del af eksisterende fiskerioperationer og indrapportering af fangstdata til myndighederne. I forbindelse med implementering af fuldt dokumenteret fiskeri vil fangstrapportering alligevel skulle foretages på trækniveau. Derved vil udgiften til dataindsamlingen være marginal i forhold til udbyttet. Ud over at bidrage med opmåling af egne fangster skal fiskerne udstyres med videnskabeligt måleudstyr, således at andre nødvendige målinger kan foretages af fiskerne, når de alligevel befinder sig på havet. Herved bliver omkostningen til disse målinger ligeledes marginal. Endvidere kan fiskerne evt. efter aftale og med passende kompensation foretage prøvetagninger uden for deres sædvanlige fiskepladser på vej til, fra og mellem disse.

De indhentede informationer kombineret med data fra andre kilder såsom videnskabelige togter, satellitdata, meteorologiske og hydrografiske modeller samt viden om marine organismers adfærd bruges til at fremstille modeller, der kan beskrive den øjeblikkelige tilstand af økosystemet i reel tid og fremskrive tilstanden i varierende detaljeringsgrad i både dage og år. Herunder at forudsige hvor fisken er og hvad den laver dér.

Ny viden om bl.a. fiskeadfærd vil kunne bidrage til innovation på det fiskeriteknologiske område og derved bidrage med mere skån- og lønsomme redskaber. Omfattende og præcise data vil mindske risikoen for at områder med store fiskeriinteresser lukkes for fiskeri på et ufuldstændigt grundlag på basis af forsigtighedsprincippet.



Figur 10. Måleprogram – Dataflowdiagram. Oprettelse af et Marint Datacenter skal sikre at de store mængder data indhentet fra de kommercielle fiskerier udnyttes ved at bringe dem på et standardiseret format til lagring og udveksling i et data warehouse.

Afsluttende konklusioner

Viden om den geografiske fordeling af fiskebestandene gennem året får central betydning for alle fremtidige former for forvaltningsplaner og -redskaber. Oskar projektet viser hvordan det er muligt at udnytte den samlede geografiske viden til at optimere fiskerierne i Skagerrak og specielt undgå uønsket bifangst af torsk og uberettiget lukninger af områder. Hjertet i projektet er et nyt geostatistisk værktøj (GeoPop modellen), som specielt udnytter forskellige togtdata til at forudsige hvordan den geografiske fordeling af alle størrelser torsk i havet (populationen) har været i perioden. GeoPop er også i stand til at bestemme variationen indenfor det enkelte træk. Denne småskala variation har vist sig at være af betydeligt omfang, hvilket også understøttes af en stor variation i næsten samtidige fangster af ungtorsk på nabostationer i Oskar togterne. Det er således dokumenteret videnskabeligt at de nuværende kriterier for RTC er uberettigede, fordi ungfisk er så klumpet fordelt, at fangsten i ét trawltræk ikke direkte kan bruges som mål for den lokale tæthed.

Resultaterne fra Oskar projektet viser også hvordan man med en bedre viden om genetik og populationsstruktur samt processer som gydning, drift af larver i havestrømmene og den juvenile vækst vil kunne forudsige fordelingen af ungfisk på en større geografisk skala flere år frem i tiden og dermed planlægge en optimal fordeling af fiskeriet og/eller brug af specielt designede trawl til at undgå bifangster af fisk under passende markedsstørrelse. I den forbindelse foreslås det at etablere et årligt tilbagevendende ungfisk togt, der gennemføres sidst/først på året med henblik på monitering af den geografiske fordeling af 0-1 årige fisk i Skagerrak. Ifølge resultaterne fra Oskar vil et sådant togt formodentlig med stor sikkerhed kunne forudsige fordelingen af hver årgang af ungfisk to år frem i tiden samt give et afgørende input til GeoPop som prædiktivt værktøj. Det vil også bidrage centralt til en forbedret bestandsvurdering. Endvidere vil den genetiske sammensætning af ungfisk indsamlet fra et sådant togt kunne bidrage væsentligt til ikke bare at få afklaret hvilke bestands-komponenter af Nordsø/Skagerrak torsken, der bundfælder sig og vokser op i Skagerrak, men også validere hypoteser vedrørende styrken af forskellige gydeområder i Nordsøen og driftsmønsteret af larver fra disse. Samtidigt er Skagerrak som overgangsområde med udprægede dybdegradienter og frontdannelse et fortrinligt område til etablering af en basis (base line) til identifikation af ændringer i fordelingsmønster, der skyldes klimaforandringer.

Der er ingen bifangstproblemer med hensyn til ungfisk i garnfiskeriet, men ellers er det ikke overraskende at der er behov for bedre data dækning for at indføre optimale selektive/ målrettede fiskerier i Skagerrak. I Oskar projektet har det kun være muligt at gennemføre 3. kvartals togtet i 2008 og de resterende tre togter i de tre andre kvartaler i 2010. År til år variationer i de fysiske og biologiske forhold giver fordelingsmønstre som afviger fra gennemsnittet og dermed også fra den generelle beskrivelse af forekomsterne som fiskernes erfaringsmæssige viden repræsenterer. Vi er for eksempel i dag ikke i stand til fuldt ud at forstå betydningen af de kolde vintre i 2009 og 2010 i forhold til 2008. Disse forhold fører til klare konklusioner mht. hvordan Oskar bør videreføres:

Det er nødvendigt at udnytte den samlede tværfaglige viden om dynamikken i arters og fisks geografiske fordelingsmønstre indenfor år og mellem år. De tilsyneladende simple spørgsmål ”Hvor er fisken og hvorfor?” er komplicerede når forvaltningen kræver viden på så lille en skala i rum og tid som det enkelte trawltræk repræsenterer. Fremadrettet er der behov for yderligere at integrere en samlet togt/moniterings indsats med indsamling og analyse af proces viden – en samlet data-indsamling der optimalt bør fortsætte i en videreudvikling af fisker-forsker samarbejde baseret på dialog. I den forbindelse repræsenterer Oskar projektet det første skridt til en sammenkobling af syv kilder til data og information: Fiskernes erfaringsbaserede viden, logbogs og positions (VMS) informationer, geografisk fordeling af artssammensætning i fangster (discard togter), viden om trawl selektion og selektive trawl, fangst pr. indsatsenhed data fra et minimalt sæsonmoniteringstogt (fire Oskar togter), forskernes moniteringsviden gennem det Internationale Bund Trawl Survey

(IBTS) og forskernes procesbaserede viden (genetik og populationsstruktur, rumlig eksplicit rekrutterings- og vækstdynamik osv.).

Der er et stort potentiale i at udnytte GeoPop modellen til en fortsat sammenkobling af data og viden. Udover de vigtige spørgsmål om torskens populationsstruktur handler det om test af modellen, udbygning af modellen til alle livshistorier fra æg og larver til voksne fisk og udvikling af modificerede modelversioner til rumlig bestandsvurdering. Der kan også blive behov for at udvide modellen med en dybdedimension, dag-nat variationer i fordelingsmønstre og rumligt overlap med konkurrerende arter eller fødedyr. Nogle af disse forhold vil blive belyst som led i afslutningen af søsterprojektet Resource for Nordsø torsken i 2012.

Selvom GeoPop modellen er god til at 'udfylde huller i data i rum og tid' er der et specielt behov for fremover at kunne udbygge indsamlingen af data på videnskabelige togter med en langt bedre udnyttelse af realtids data fra det kommercielle fiskeri. Det vil kunne implementeres med et Marint Data Center som skitseret i Fig. 10 og specielt hvis programmet for fuld dokumenteret fiskeri udbygges til sensor baseret fiskeri således at for eksempel temperatur rutinemæssigt måles på trawlet.

Tak

Projektet blev finansieret af Ministeriet for Fødevarer, Landbrug og Fiskeri, Den Europæiske Fiskerifond og DTU Aqua. Vi vil gerne takke Kurt Madsen fra Danske Fiskeres Producent Organisation for initiativet til projektet på vegne af Danmarks Fiskeriforening (DF) og Claus H. Pedersen, Jan Hansen og Henrik S. Lund fra DF for deres engagement og deltagelse i dette samarbejdsprojekt. Vi vil også gerne takke de tre skippere Jesper Nielsen, Jens Poulsen og John Jacobsen og deres besætninger ombord på fartøjerne HG-350 *Luna*, FN-234 *Canopus* og S-544 *Dortigi* for deres samarbejde og vidensdeling. Til sidst vil vi gerne takke alle de DTU medarbejdere der har været involveret i projektet, specielt Henrik Mosegaard for gode ideer og konstruktivt input gennem hele projektet og til Jan Pedersen, Søren L. Grønby, Per Christensen og Hans J. Olesen for deres store indsats i forbindelse med togterne.

Reference

Kristensen, K. (2008). Statistical aspects of heterogeneous population dynamics. Ph.D. thesis, University of Copenhagen.

Abstract

Knowledge about the geographic distribution of fish stocks during a year will be of central importance for all future management plans and -tools. The Oskar project shows how it is possible to utilize the sum of geographic knowledge to optimize the fisheries in Skagerrak and especially avoid unwanted bycatch of cod and unjustified closure of areas. The core of the project is a new geostatistical tool, the GeoPop model, which makes particular use of different survey data in order to predict how size-specific geographic distributions of cod in the sea (the population) have been in this period. GeoPop can also estimate the variation within a single haul. This small scale variation is considerable, which is supported by a big variation in almost simultaneous catches of young cod at neighbouring stations in the Oskar survey. Thus it is scientifically documented that the present criteria for Real Time Closure are unjustified, since the young fish are so patchily distributed that the catch in one haul cannot be used directly as proof of the local density.

Furthermore, the results of the Oskar project show how it will be possible to predict the distribution of young fish on a larger geographic scale some years from now, and thus plan an optimal distribution of the fishery and the use of specially designed trawl to avoid bycatch of fish below trade size. A yearly monitoring of the geographic distribution of 0 to 1 year old cod in Skagerrak will also contribute significantly to an improved stock assessment.

It is necessary to utilize the collected interdisciplinary knowledge about the dynamics of the geographical distribution patterns of the species within years and in between years. The apparently simple questions ”Where are the fish and why?” are complex when the management demands knowledge on such a small scale in space and time that a single trawl haul represents. In the future there is a need for further integration of a joint survey/monitoring effort with the collection and analysis of process knowledge – a joint data collection which optimally should continue into a further development of the dialogue based collaboration between scientists and fishermen. The Oskar project constitutes the first step towards linking seven sources of data and information: the fishermen's experience based knowledge, logbooks and VMS-positioning information, geographic distribution of the species composition in catches from discard trips, trawl selection and selective trawls, catch data from minimal season monitoring (four Oskar surveys), scientists' monitoring- and process based knowledge.

Although the GeoPop model is useful to ”fill in holes in data in space and time” there is a special need to be able to extend the collection of data on scientific cruises with a far better utilization of real time data from the commercial fishery. It could be implemented with a Marine Data Centre, especially if the programme for fully documented fishery is expanded to sensor based fishery, so for instance temperature routinely is measured on the trawl.

Synthesis

Introduction

The aim of this project is to establish the knowledge about geographical distribution of the target species in Skagerrak during a year, which makes the fishermen capable of organizing fisheries that are sustainable with a minimum of discard and unwanted bycatch of Atlantic cod and can be conducted without drastic reductions or unjustified closure of areas.

The demersal fisheries in Skagerrak constitute one of the major parts of the fisheries in Denmark with an annual landing value of approximately 300 mill. DKK. They are targeting a suite of stocks of which the economically most important species Norway lobster, cod, plaice and saithe contribute with *c.* 70 % to the total landing value. The demersal fleet is dominated by trawlers with regard to the number of vessels as well as kilo-watt days and landing value. Norway lobster and saithe are landed exclusively by trawlers, whereas cod are targeted by trawlers and gillnetters, and to a lesser extent by Danish seiners. Plaice are mainly landed by Danish seiners, but to some extent also by trawlers. During the latest decades, the demersal fleet in Skagerrak has been subjected to dramatic changes as regards the number of vessels and kilo-watt days. In particular, the cod related fisheries have decreased concurrently with the significant restrictions in TAC for cod and other limitations in the fisheries due to the poor status of the cod stock. The result is that the major part of cod (60-70 % in 2008-2010) is landed in fisheries that are not specifically targeting this species, while 60-80% of Norway lobster, plaice and saithe are landed by dedicated fisheries. The implementation in 2007 of FKA (‘fartøjs kvote andele’ ~ owner based quota system) in the demersal fisheries resulted in a further concentration of the cod quota among vessels, which already held the major part of the quota in Skagerrak. This is reflected in small but increasing gillnet and Danish seine fisheries targeting cod.

Improved information about the geographical distribution during a year of cod as well as of other targeted stocks is an important prerequisite for the optimization of fisheries subjected to future management plans and tools. With a specific knowledge about the species and body size compositions in an area with an important target species, fisheries at locations with unwanted species and size groups may more easily be avoided and/or specially designed selective trawls may be used. At present, not more than 10 % by weight of young gadoids are allowed in each individual haul in the trawl fisheries. Higher values will cause a temporary closure for fishery in a 50 nmi^2 area, the so called Real Time Closure (RTC).

Focussing on cod, the objective of the present project is to work out the type of knowledge about the geographical and temporal distribution dynamics that can maximize the exploitation of the fisheries resources in the mixed as well as the species specific fisheries in Skagerrak, in such a way that the fisheries are sustainable with a minimum of discard and unwanted bycatch of cod and can be conducted without drastic reductions or unjustified closure of areas.

Methods

The overall objective was pursued by combining the results obtained from the following work packages (Fig. 1):

Fishermen's experience based knowledge obtained from their fisheries (work package A)

The fishermen's knowledge on the whereabouts of the individual species throughout the year was obtained and systematized in co-operation with the scientists in two workshops. The result is a series of GIS maps with areas marked for each species and with a temporal resolution that reflects the fishermen's perception of the species specific dynamics of the geographical distribution.

The demersal fisheries (work package B)

Combining information from logbooks and positional (VMS) data, the geographical distributions of effort, catch rates and species compositions of landings were described for each quarter of the year in 2005-2010. Information from discard surveys was used to demonstrate the geographical distribution of the species composition in the *catches*. The commercial fleet was split into segments by gear type and landing profile (species composition), and the development of the demersal fleet subjected to changing management approaches during the last decade was described.

Trawl selection and selective trawls (work package C)

The trawl types employed in the Skagerrak fisheries of today and their selective characteristics were described together with the possible development in future trawl design in preparation for the coming challenges to the fisheries in Skagerrak. In addition, experimentally estimated selection parameters were used to convert the observed size distribution of each gadoid species caught during the Oskar surveys (with 90 mm cod end) into the size distribution in the commercial fisheries with 120 mm mesh size (work package D). Finally, selection parameters were used in the GeoPop model (work package F) to convert the size distribution of cod in IBTS and Oskar surveys into the size distribution in the sea.

Oskar surveys (work package D)

Within each quarter of the year, a monitoring survey with two trawlers and a gilnetter was carried out with the purpose of collecting information on the geographical and seasonal distribution of catch rate and composition in Skagerrak as well as relating these variables to predictors like water depth and temperature. Additionally, catch rates by size group for each target species entered as input to the GeoPop model (work package F) and for identification of possible problematic areas with a high density of young fishes.

Scientists' monitoring and process based knowledge (work package E)

Skagerrak is subjected to two annual scientific monitoring surveys (IBTS: International Bottom Trawl Survey) in the first and third quarter of the year, respectively. The purpose of IBTS is to provide a recruitment index for the five commercially important gadoids plus herring, sprat and mackerel. Catch rates by size group of cod from each haul entered as input to the GeoPop model (work package F).

Information about size distributions obtained from the so called discard surveys were used together with Oskar survey data to demonstrate the geographical distribution of gadoids by size group in the catch and to identify possible problematic areas with a high density of young fishes.

A range of biological processes are either of direct importance to the geographical distribution of each species or can be used to infer about the distribution dynamics. Knowledge about these processes will permit more valid and long-term predictions. Here, the focus was on three research areas on cod:

Genetic analyses and stock composition (work package E1)

Information about more or less separated stock components of cod and their mutual distribution dynamics will enable fisheries management of stocks rather than of areas including organization of fisheries targeting the specific stock components. It is, therefore, interesting to examine which of the stock components that contributes to the recruitment of cod in Skagerrak. In the present project, the genetic composition of spawning cod from two locations in the border area between Skagerrak and the North Sea were compared to each other as well as to spawning cod from other locations in the North Sea.

Dispersal of cod larvae to the settlement areas (work package E2)

An individual based model of dispersal of cod eggs and larvae, coupled to an oceanographic physical model and a probability function for cod spawning areas, was developed and tested in the Nord Sea / Skagerrak. The model was used to (1) simulate the temporal and geographical distribution dynamics of cod larvae until settling in Skagerrak (2004-2007) and (2) identify spawning areas (and stock components, cf. work package E1) contributing to the recruitment of cod in Skagerrak.

Growth dynamics of juvenile cod (work package E3)

Growth rates (obtained by otolith readings) of juvenile cod from three areas in Skagerrak were compared. Possible growth differences would indicate partly the suitability of the respective areas as nursery habitats for cod and partly the home range of juvenile cod after settling.

Geostatistical population model (GeoPop) (work package F)

There is a need for a tool that has the capability to transform survey data and other catch data into a graphic description of the current geographical distribution of the population in the sea, and in a way that makes it possible to test statistically the importance of different predictor variables like water depth and temperature for the precision of this description. Such a tool called the GeoPop model (geostatistical population model) was developed in the Oskar project in continuation of a Ph.D. study (Kristensen, 2008).

The idea is to use length-frequency data from individual hauls in Oskar, IBTS, REX etc. to visualize a geographical relief of the current density distribution of small and large cod in the sea. It is important to realize that this method provides distributions also at times and locations where there is no data information. Using IBTS and Oskar survey data and including the selection curves for the employed trawls, the parameters of the model for cod are estimated. The GeoPop model also takes into consideration the variation on a small geographical scale; for example, two consecutive neighboring hauls performed within a short time interval with the same fishing gear may well show very different size distributions of cod in the catches. Thus, use of the GeoPop model enables the examination of a core question in the Oskar project: based on a single haul, does it make sense at all to close an area for fishery (RTC)?

Integrated fishery and management in the marine ecosystem (work package G)

As project idea work package G collects all the Oskar elements in proposing the establishment of a Marine Data Centre where data can be used to improve fish stock assessments, selective fishing gears and production of short and long term fishery forecasts (from days to years) with the purpose of making the fishermen capable of organizing and optimizing ecologically and economically sustainable fisheries.

The basic idea is to make use of commercial fishing operations for a comprehensive collection of data on the current condition of the marine ecosystem. Expected costs are marginal as e.g. reporting of catch data will anyway be done at haul level in connection with the implementation of fully documented fishery. Further, as a basis for a modern sensor based fishery the fishermen will receive scientific monitoring equipment.

It is expected that integrated fishery and management in the marine ecosystem can evolve by a combination of sensor based fisheries, catch quota management, Oskar, ecosystem management and scientific surveys.

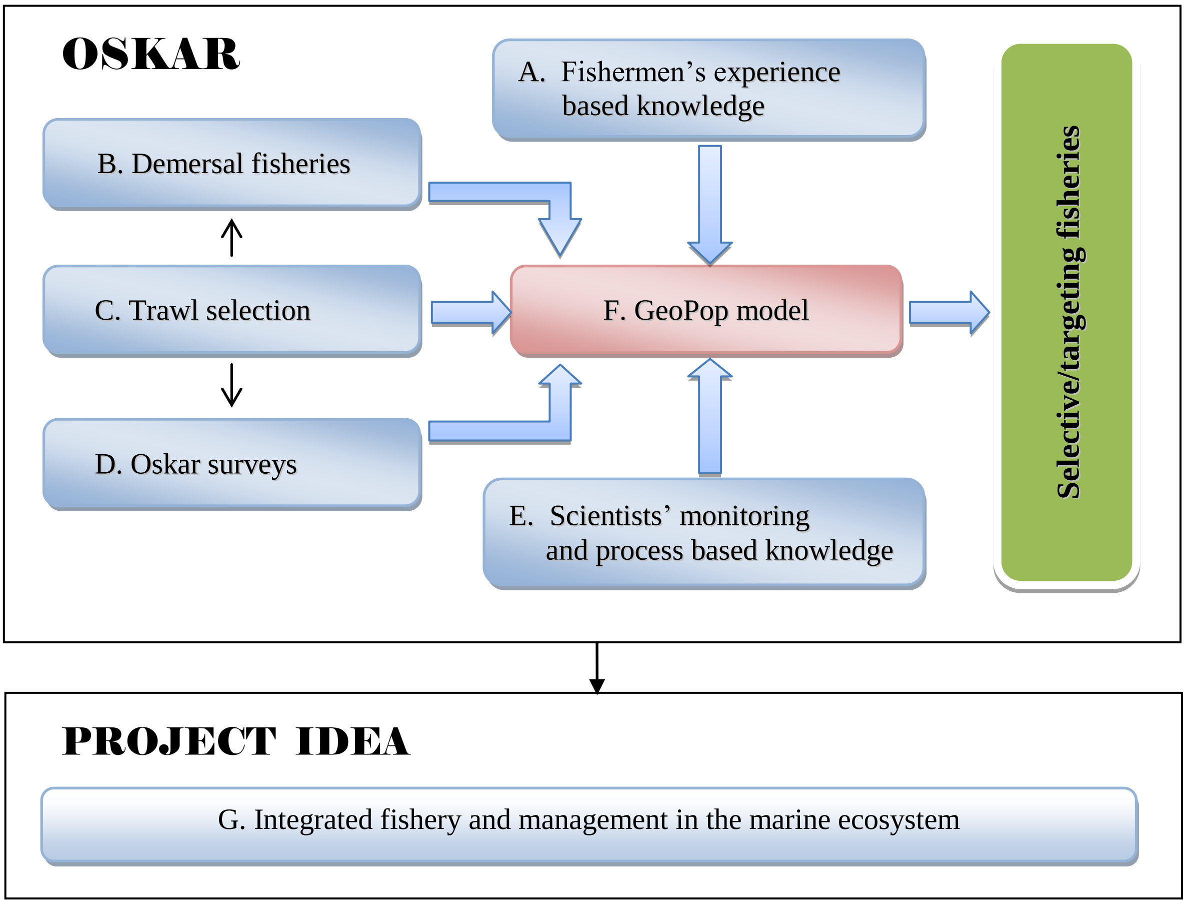


Figure 1. The work packages and their interrelationships.

Results and discussion

In Fig. 2(a)-2(d), the fishermen’s (trawlers and gillnetters) experience based knowledge about the geographical distribution of the four most important target species cod, Norway lobster, saithe and plaice during a year is compared to the distribution of the commercial landings (vessels >15 m). Considering that the Norway lobster fisheries are the primary drivers of the overall effort distribution of the demersal fleet, the distribution of the commercial landings is in general quite well reflected by the fishermen’s knowledge about the distribution in the sea of these species.

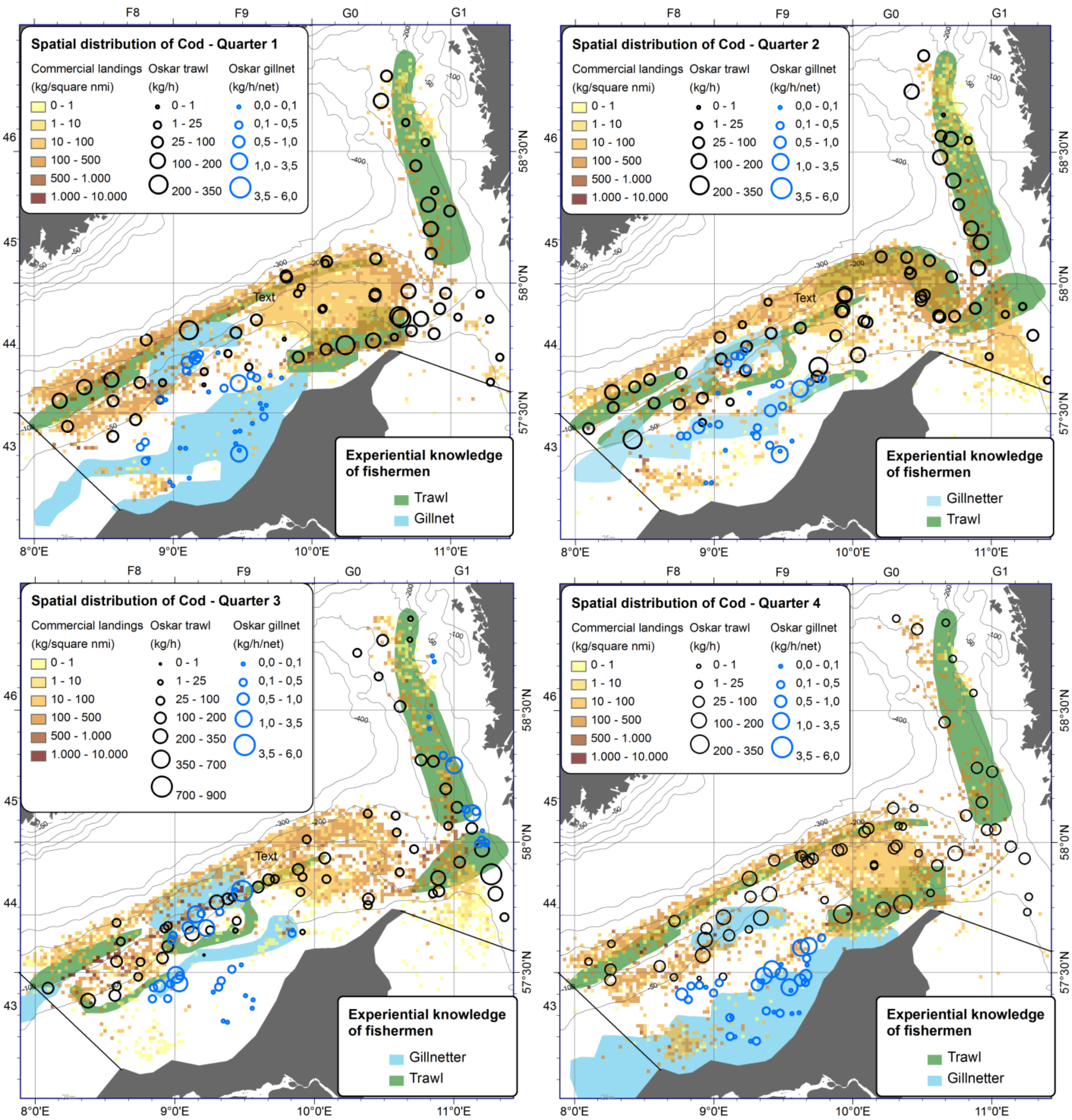


Figure 2(a). Fishermen’s (trawlers and gillnetters) experience based knowledge about the geographical distribution of **cod** in Skagerrak (green and blue areas, respectively) in each of the four quarters of the year are compared to total landings of vessels > 15 m in 2008-2010 (coloured 1x1 nmi squares) and catch rates of the trawlers and gillnetter during the Oskar survey (black and blue circles, respectively).

The high catch rates of cod by the Oskar gillnetter in shallow water in Jammerbugten during the fourth quarter of the year are located just outside the area pointed out by the fishermen [Fig. 2(a)]. This deviation can be explained by the distribution dynamics: it is not until the end of the quarter that large cod actually are migrating towards the shore. The large commercial landings of cod north of Skagen outside the areas designated by the fishermen result from the high effort allocated to the Norway lobster fisheries in that particular area.

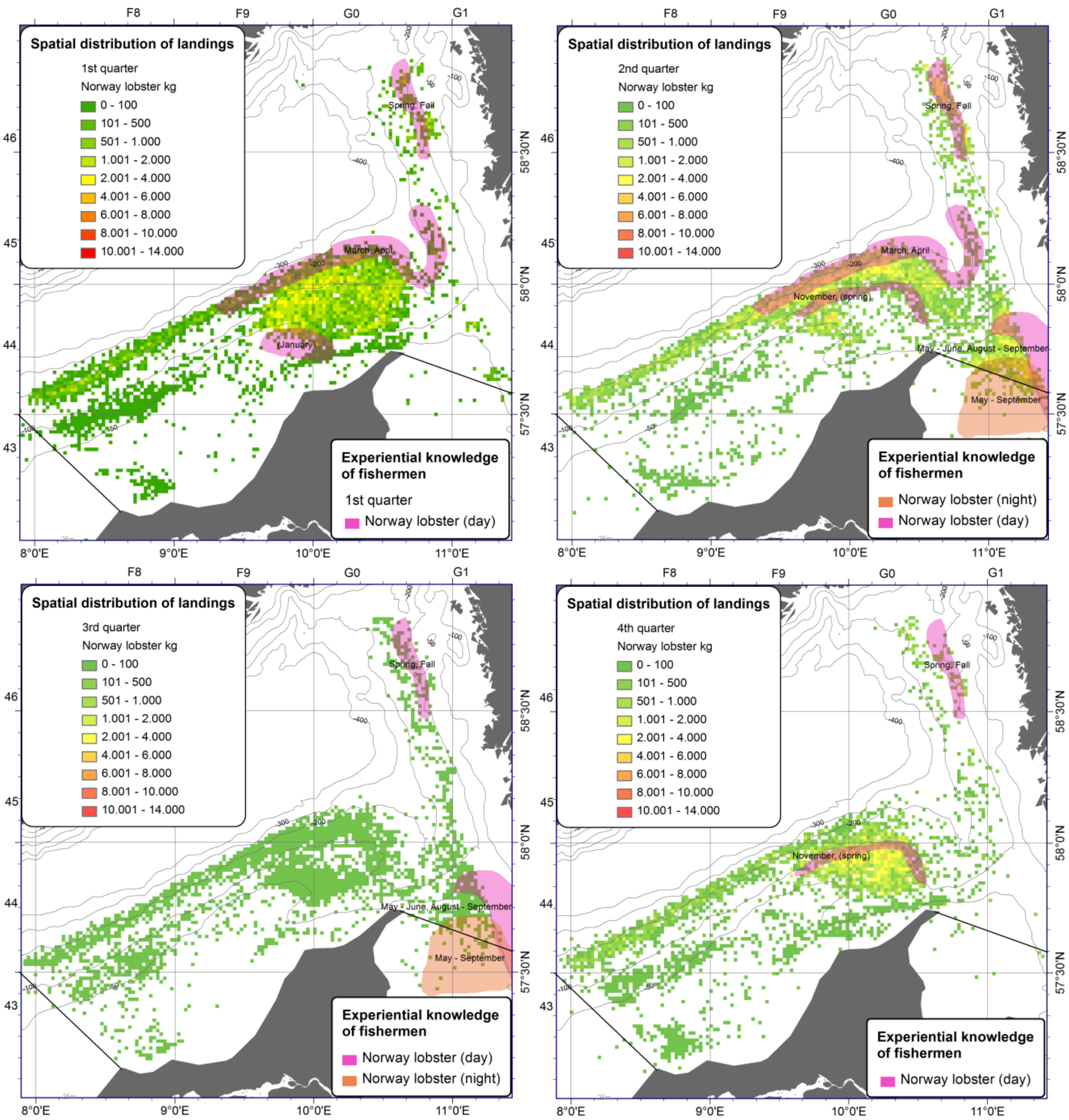


Figure 2(b). Fishermen’s (trawlers) experience based knowledge about the geographical distribution of **Norway lobster** in Skagerrak (pink and orange areas) in each of the four quarters of the year are compared to total landings of vessels > 15 m in 2008-2010 (coloured 1x1 nmi squares).

The distribution of commercial landings of Norway lobster ranges far beyond the western limit shown by the fishermen [Fig. 2(b)]. Further, significant landings of Norway lobster come from an area between Hirtshals and Skagen, which has not been pointed out by the fishermen.

The fishermen's knowledge about saithe is well reflected by the total commercial landings as well as by trawl data obtained from the Oskar surveys [2(c)].

The geographical distribution of plaice landings is not driven by the effort allocation of the Norway lobster fishery. Fig. 2(d) shows that the major part of the landings originates from shallow water.

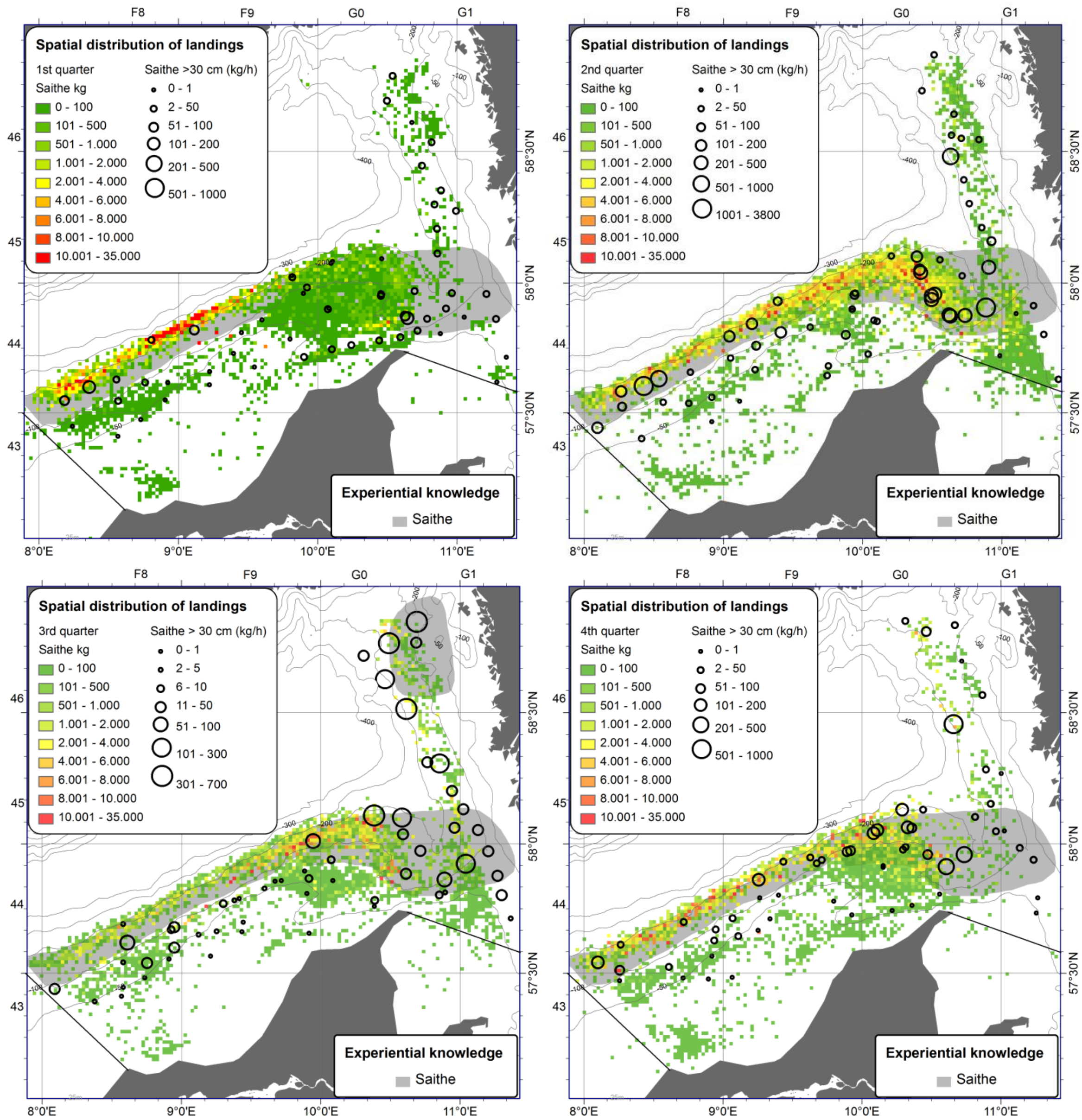


Figure 2(c). Fishermen's (trawlers and gillnetters) experience based knowledge about the geographical distribution of **saithe** in Skagerrak (coloured areas) in each of the four quarters of the year are compared to total landings of vessels > 15 m in 2008-2010 (coloured 1x1 nmi squares) and catch rates of the trawlers during the Oskar survey (black circles).

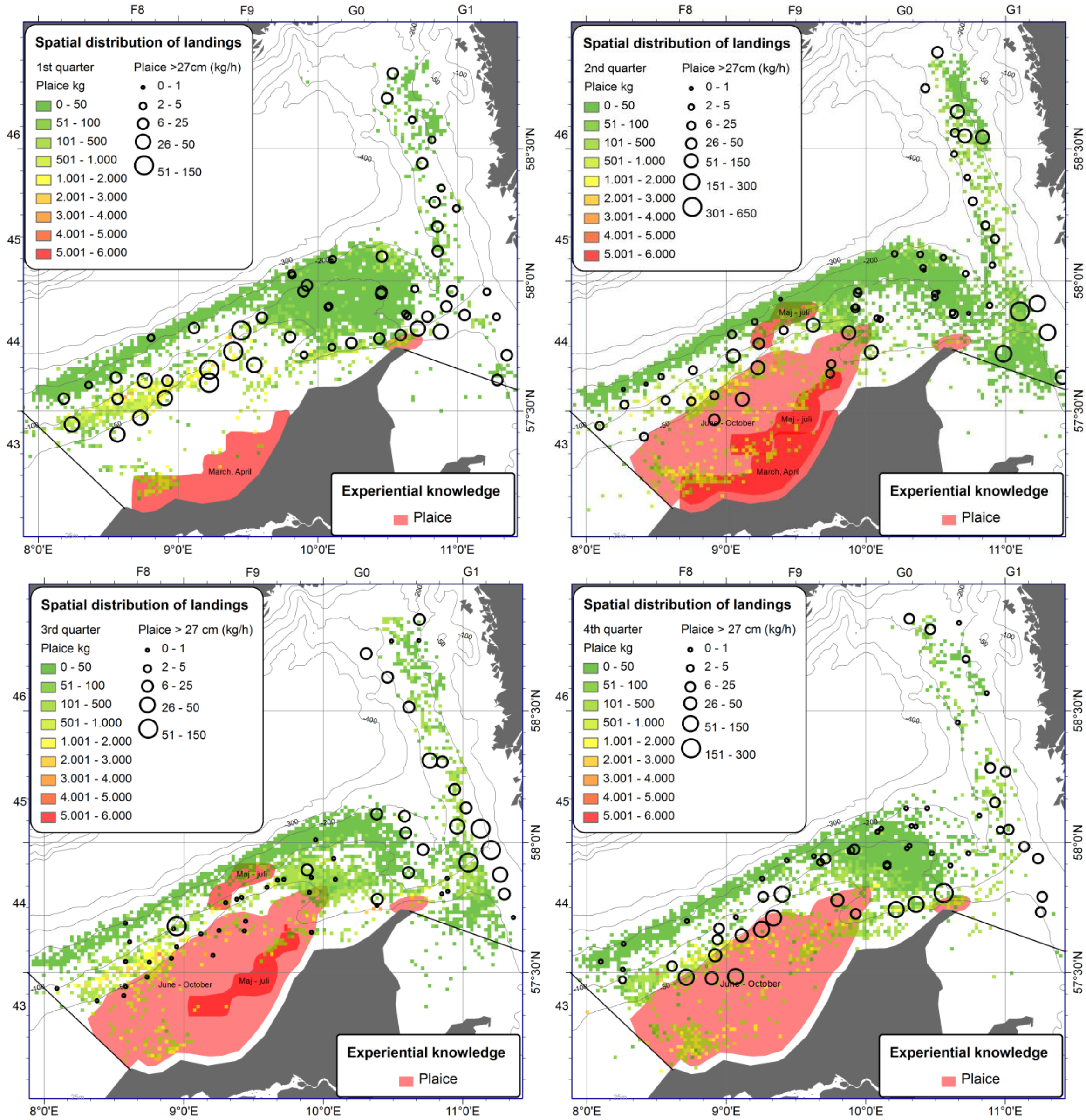


Figure 2(d). Fishermen's (trawlers and gillnetters) experience based knowledge about the geographical distribution of **plaice** in Skagerrak (coloured areas) in each of the four quarters of the year are compared to total landings of vessels > 15 m in 2008-2010 (coloured 1x1 nmi squares) and catch rates of the trawlers during the Oskar survey (black circles).

The variation in the size distribution of cod obtained from neighboring trawl stations is shown in Fig. 3. The size distributions are distinctively different and so are the shares of young cod relative to the total catches of cod. This indicates that it would be difficult or impossible on the basis of the size distribution in a single haul to select one area for another in order to avoid excessive bycatch of young fish.

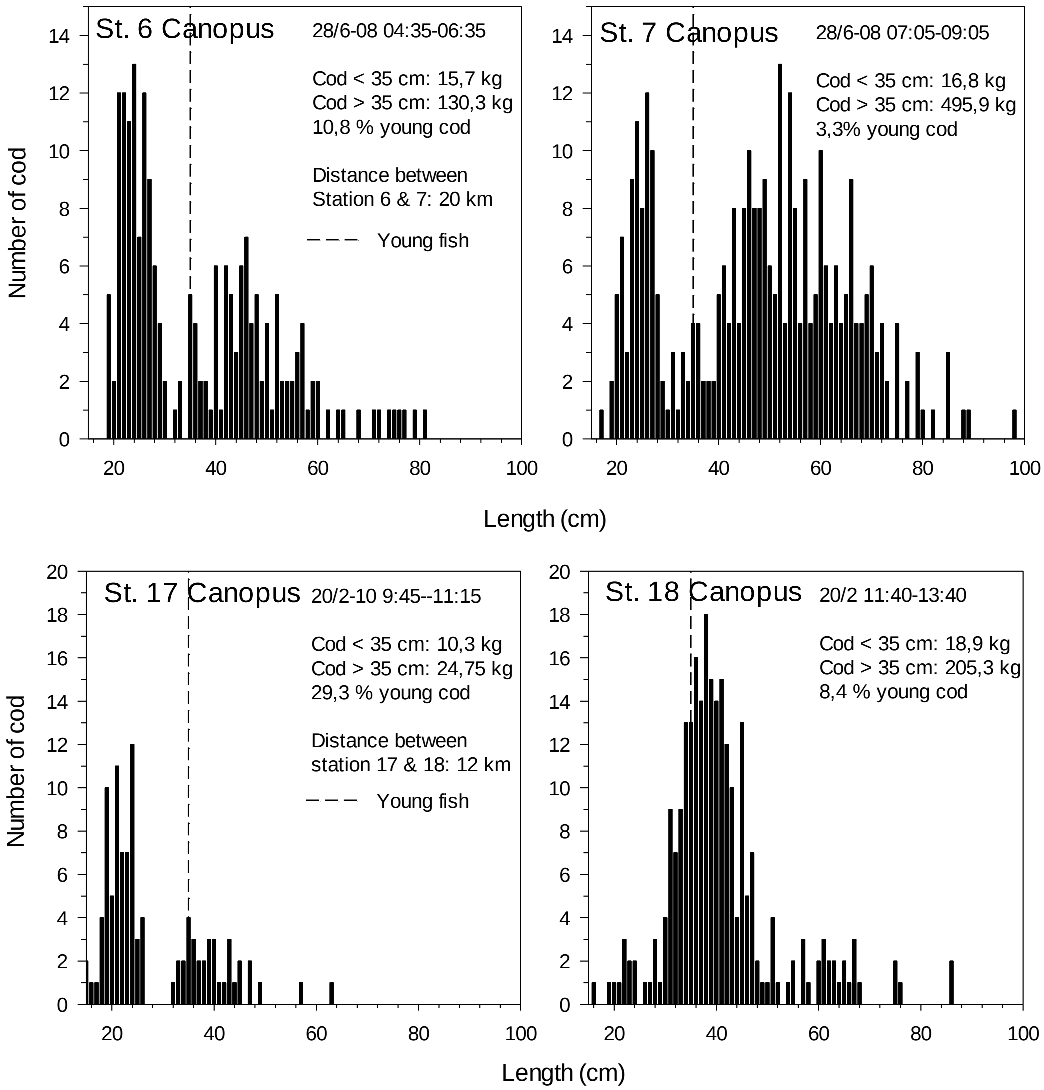


Figure 3. Length-frequency distribution of cod caught by the trawler *Canopus* at the two neighbor stations 6 and 7 during the quarter 3 Oskar survey 2008 (top) and the two neighboring stations 17 and 18 during the quarter 1 Oskar survey 2010 (bottom). In addition, percentage of young cod relative to total catch of cod is shown.

Analyses of trawl data from the Oskar surveys indicate that large landings, in general, do not imply high catch rates of undersized fish (work package D). The exception is cod for which there is a significant positive correlation between catch rates of fish below and above minimum landing size (Fig. 4). This indicates that the fisherman targeting cod may have a problem with a bycatch of young cod (unless the employed fishing gear is sufficiently selective). In contrast, by choosing appropriate locations and times of the year, the mixed trawl fishery and the trawl fisheries targeting saithe and Norway lobster have the possibility to optimize the catch composition without necessarily increasing unwanted bycatches of undersized fish.

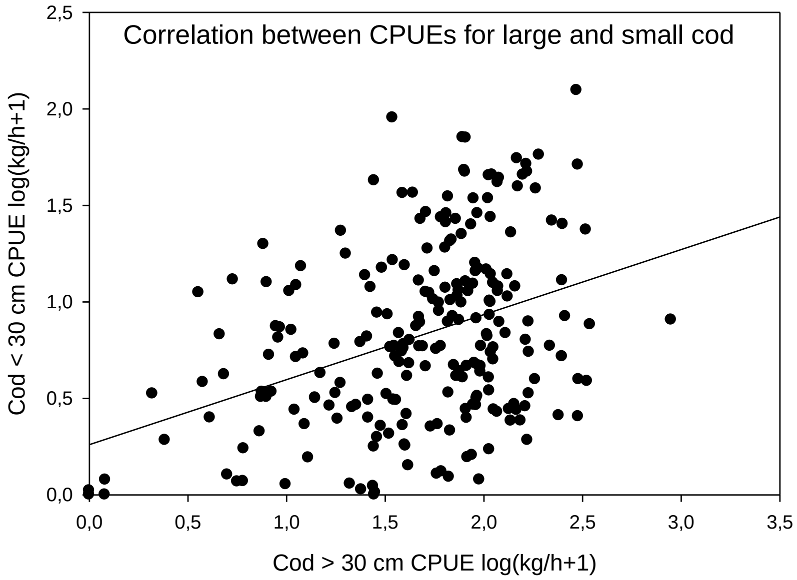


Figure 4. Catch rates of undersized cod plotted against catch rates of cod above minimum landing size. Trawler data from all Oskar surveys combined. The correlation is significant (slope=0.34; P<0.005).

Cod constituted the major part of the catches obtained by the gilnetter in all Oskar surveys (Fig. 5). Additionally, saithe and plaice above minimum landing size contributed to the catches in respectively two and four of the surveys, and beyond this also some haddock. Whiting did not form a part of the catch. Other species were represented by ling and lemon sole. Bycatch of undersized commercial fishes were insignificant with a maximum value of less than 0.4 %.

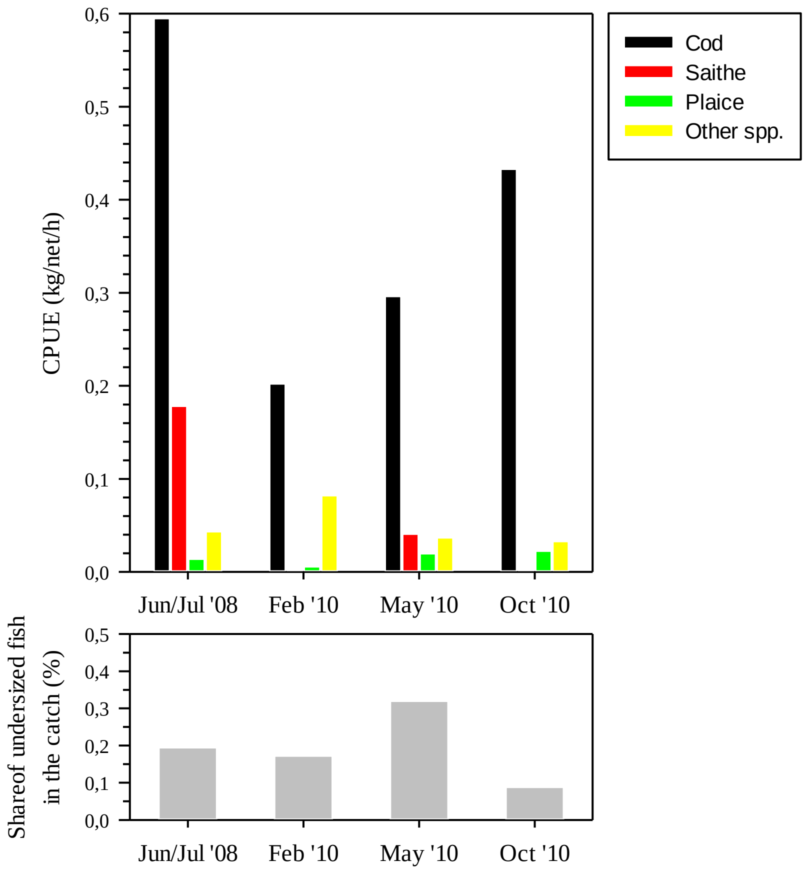


Figure 5. Catch rates of commercial species above minimum landing size obtained by the OSKAR gilnetter (top) and shares of undersized fishes in the catches (bottom).

The share (by weight) of young fish relative to the total catch of the four commercial gadoids cod whiting, haddock and saithe in each trawl haul during the Oskar surveys may give an indication of problematic areas in Skagerrak as regards Real Time Closures (RTC). It is just an indication because the Oskar survey in contrast to the commercial fishery was targeting cod and therefore used a large vertical gap in the trawls. Therefore, it is not remarkable that the Oskar based maps in Fig. 6(a) display far larger red areas with a high share of young gadoids than do the discard based maps in Fig. 6(b). The results in Fig. 6 show that large areas are potentially problematic with high shares of young fish, whereas only a few hauls with catch above the minimum size required for effectuation of a RTC (work package D), would actually result in a closure. Recalculating the length-frequency distributions to that of the retained catch in a standard trawl with 120 mm cod end, the problematic areas shrink and the green areas with small shares of young fish constitute the major part of the investigated area except from quarter 4 (Figs 39-42 in work package D).

Quick guide for interpretation of the maps in Fig. 6: Green triangles in green area indicate <10 % young fish in the catches of gadoids. Green triangles in orange or red areas indicate catches <200 kg but >15% young fish in the catches in the area; increase of haul time would probably be a problem. Yellow circles in yellow, orange or red area indicate catches between 200 kg and 300 kg, and >10 % young fish in the area. Red circles in orange or red areas indicate catches >300 kg and >15 % young fish in the area.

It is important to notice that the maps show significant differences on a quarterly basis. For example, the demarcation of the Oskar area towards north-east in the first and fourth quarter of 2010 [Fig. 6(a)] is distinctly red as opposed to the average of the catches obtained from the discard surveys in the corresponding quarters for 2008-2010 despite the 2-4 times longer haul durations. Such differences and variations in catch composition among larger areas as well as between neighboring hauls (Fig. 3) indicate that, for example, RTC criteria for the youngfish population in the sea should be based on a solid real time data material and a tool that can translate local catches into knowledge about the local density of youngfish (cf. The GeoPop model). Therefore, the aggregated distribution map in Fig. 6(c) should be interpreted with caution.

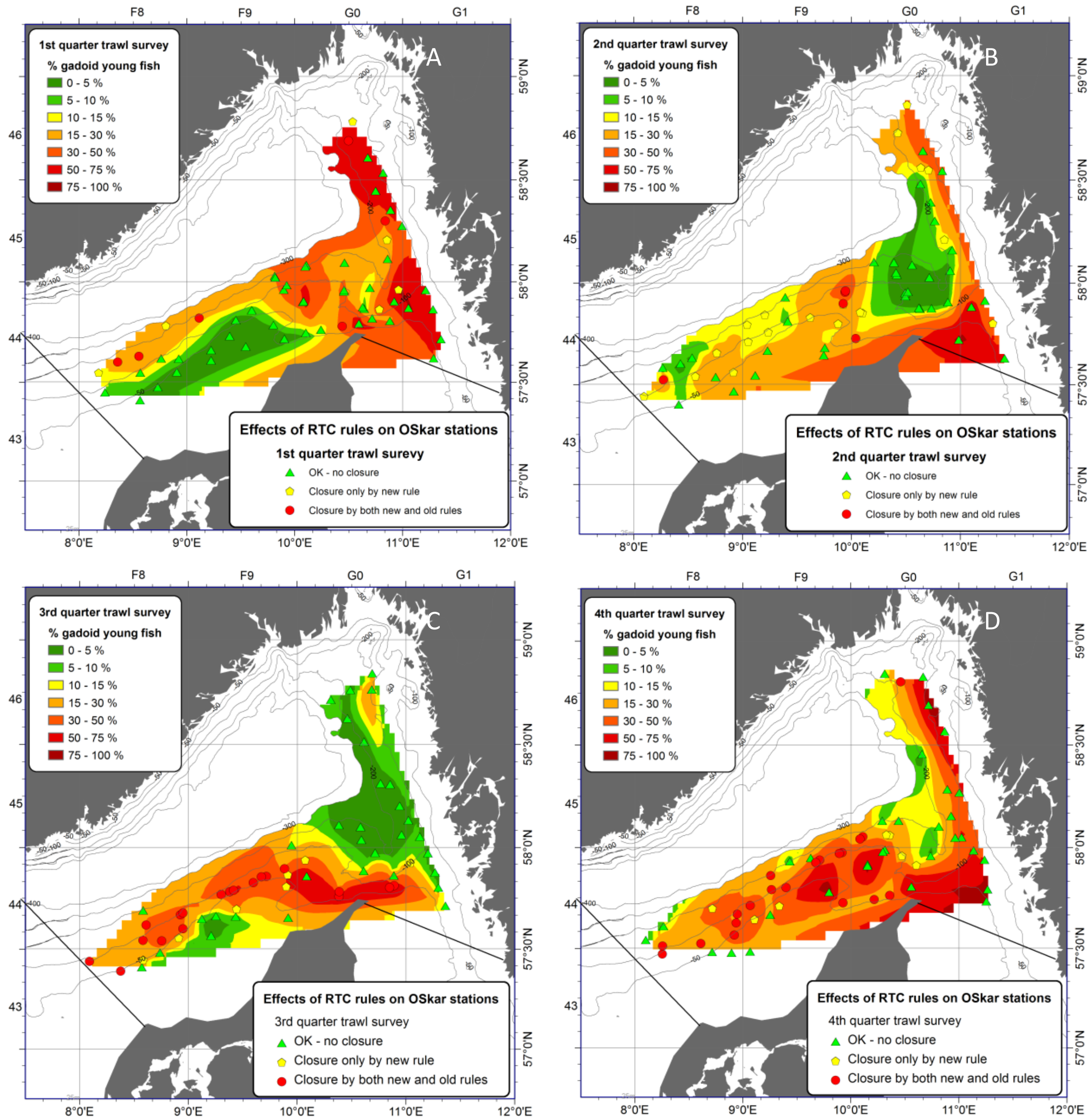


Figure 6(a). Share (% weight) of gadoid young fish (cod, whiting, haddock and saithe) relative to total gadoid catch by haul for the two trawlers during the **Oskar survey** in each of the four quarters of the year. Coloured areas are interpolations (natural neighbour) in GIS of observed values for hauls with more than 10 kg gadoids in the catch. ▲ indicates hauls that would not cause a real time closure (RTC); ● indicates hauls that would cause a RTC according to the new rules (13. August 2011; total catch of gadoids >200 kg and share of young fish >10 %); ● indicates hauls that would cause a RTC according to both the new rules as well as the old rules (total catch of gadoids >300 kg and share of young fish >15 %).

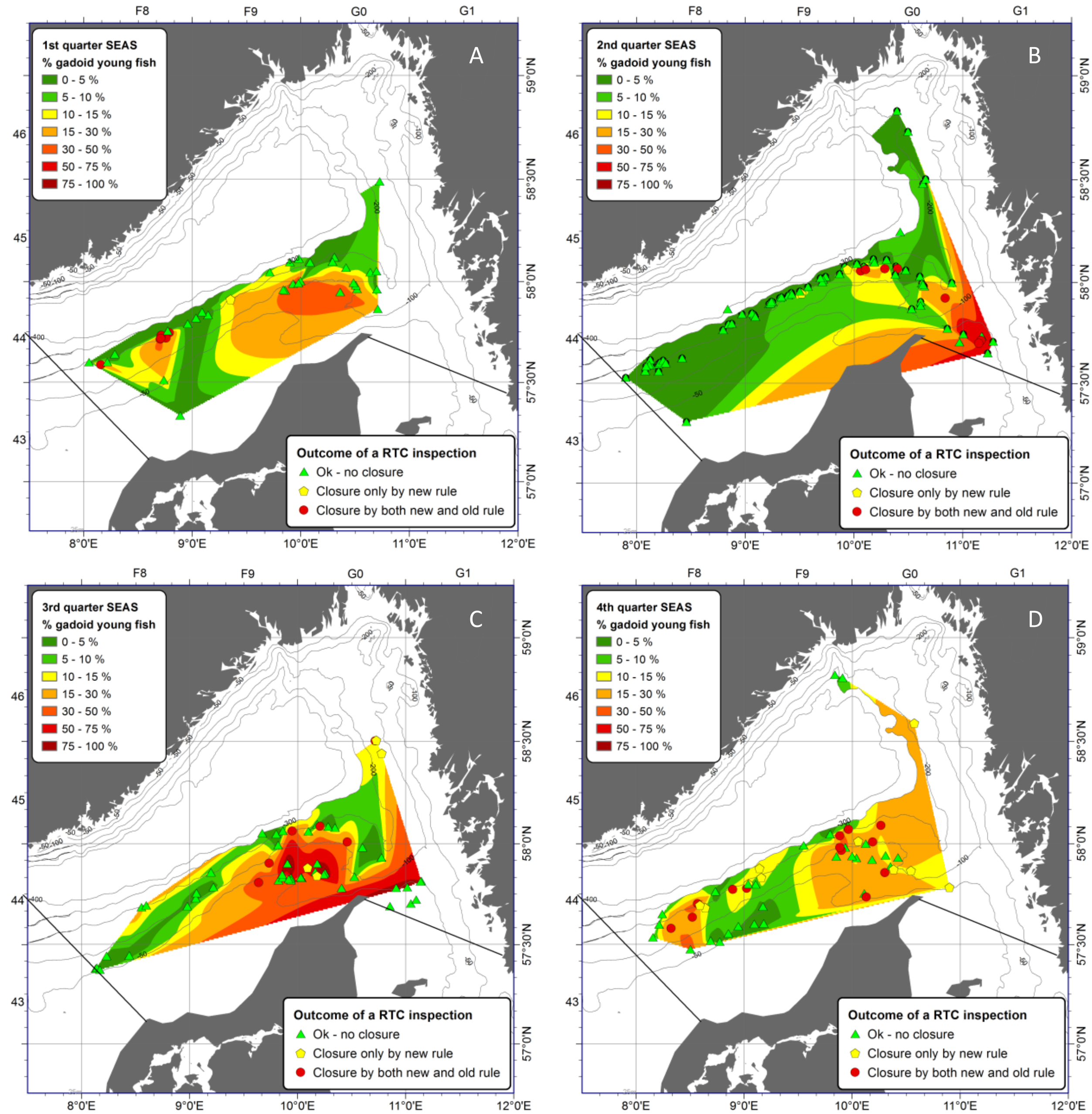


Figure 6(b). Share (% weight) of gadoid young fish (cod, whiting, haddock and saithe) relative to total gadoid catch by haul for all OTT and OTB trawlers (with cod end mesh sizes between 90 mm and 120 mm) during the **discard survey** in each of the four quarters of the year. Coloured areas are interpolations (natural neighbour) in GIS of observed values for hauls with more than 10 kg gadoids in the catch. ▲ indicates hauls that would not cause a real time closure (RTC); ● indicates hauls that would cause a RTC according to the new rules (13. August 2011; total catch of gadoids >200 kg and share of young fish >10 %); ● indicates hauls that would cause a RTC according to both the new rules as well as the old rules (total catch of gadoids >300 kg and share of young fish >15 %).

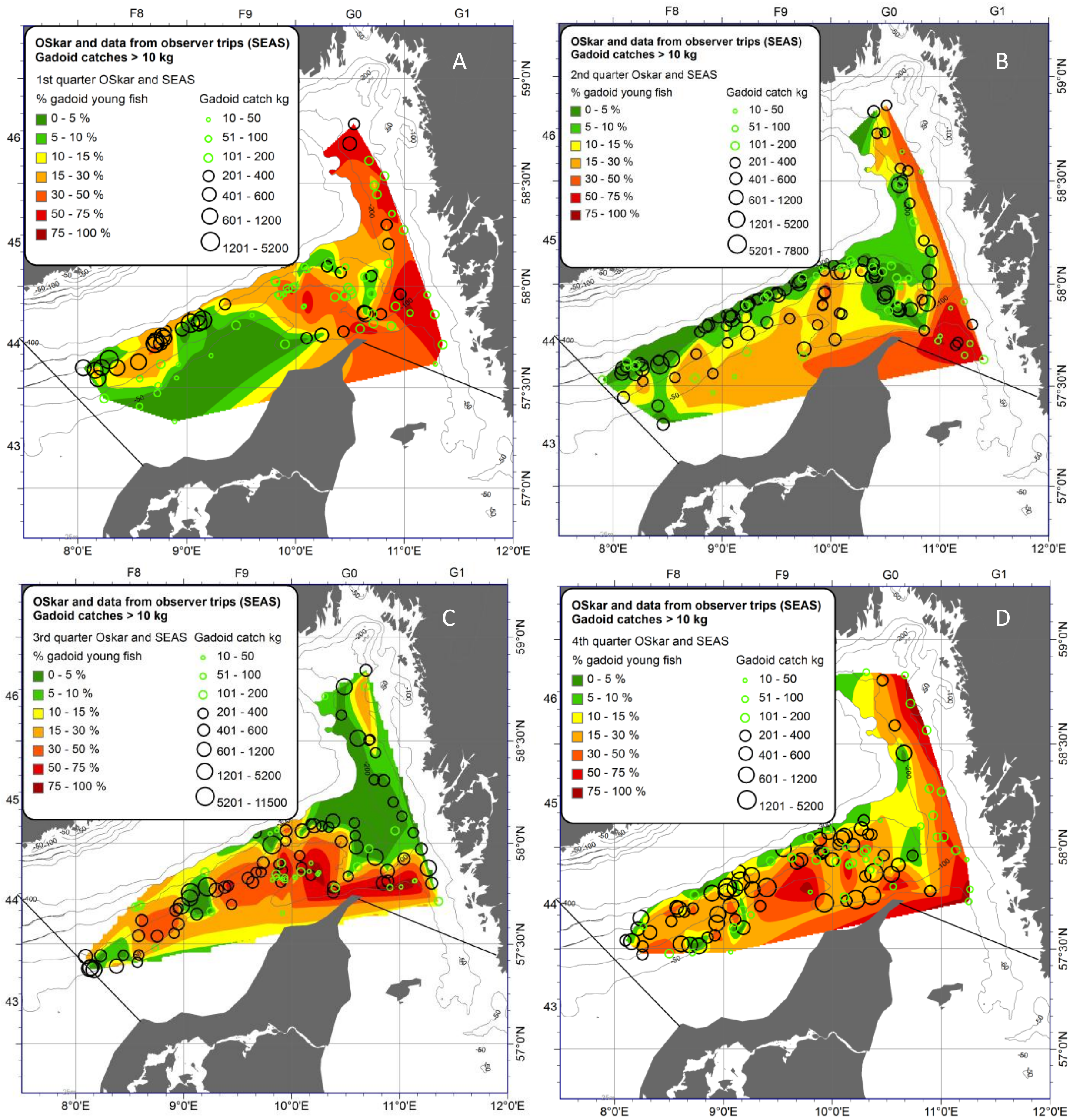


Figure 6(c). Share (% weight) of gadoid young fish (cod, whiting, haddock and saithe) relative to total gadoid catch by haul for **Oskar and discard surveys combined** in each of the four quarters of the year [see Figs 6(a) og 6(b)]. Coloured areas are interpolations (natural neighbour) in GIS of observed values for hauls with more than 10 kg gadoids in the catch. Catches of less than 200 kg are indicated by green circles to show that the colours of these areas are based on relatively small gadoid catches.

The result from the geostatistical population model GeoPop is a film, which on a weekly basis shows the relative distribution in Skagerrak of specific size groups of cod, for example juveniles below 30 cm. The images in Fig. 7 depict the results based on Oskar survey data in the first week in each quarter of the year throughout the project time (2008-2010). Inclusion of IBTS data does not, in general, change the images for the different size groups of cod (work package F), which points to model consistency. The results differ in June-July 2008 and May 2010, but in these cases there are no temporal overlaps between Oskar and IBTS hauls. The difference arises from an increased precision because of the improved temporal coverage obtained by use of both datasets. The months in which both datasets enter, show remarkably similar images of the geographical distribution of the different size groups.

It is exactly these relationships that make us having confidence in the model and its results. If this was not the case, it would be necessary to extend the model with hypotheses about the causes of, for example, different catchabilities for large cod of the GOV trawl used in IBTS and the standard trawl used in Oskar. We expect that these aspects will come up for the North Sea cod because the difference between IBTS catch rates on smooth bottom and REX/RESOURCE catch rates of large cod on rough bottom is more distinct here. In the RESOURCE project, it will be statistically tested whether the gear efficiency decreases for large cod – a relationship that is not examined in the Oskar project. In addition, there is only 1-2 IBTS hauls per ICES square in the North Sea as compared to significantly more IBTS hauls in Skagerrak and especially in Kattegat. These questions are beyond the scope of the Oskar project and will be addressed in the sister project RESORCE in 2012, which as an extension of the REX projects also focuses on stock assessment.

However, the most important result from the GeoPop model in the present study is probably the effect of the dominating variability on a small geographical scale, which is also demonstrated by the differences in size distribution among neighboring hauls in Figure 3. Comparing maps with expected bycatches, the consequence of this is quite clear. Fig. 8 indicates that it is possible to control the total bycatch of a fleet by allocating the hauls so that the red areas are avoided. Then, the bycatch from all hauls combined will be <15%. Conversely, according to Fig. 9, it is impossible to obtain a similar control for each individual haul; the risk of getting an illegal bycatch will always be significant.

Area specific population structure, recruitment, growth, mortality and migration are necessary entities to keep track of in order to understand the dynamics of the geographical distribution for the different size groups and to develop a model that, with an appropriate precision, is able to predict the distribution dynamics a season or year ahead. In the Oskar project, we initiated some studies on recruitment and growth, which demonstrate the utility of knowledge about these processes. The genetic studies (work package E1) showed that the spawning population along the edge of the Norwegian trench from the western part of the border between Skagerrak and the North Sea differs from that on the Danish side, which in return is similar to samples from other parts of the North Sea. This can be explained from the results of the model study (work package E2) on the dispersion by water currents of cod larvae from the spawning sites to the settling areas. It appeared that the pulses of larvae entering Skagerrak originate from western and southern locations in the North Sea, whereas larvae from the Norwegian trench are transported northward and therefore do not contribute to the recruitment in Skagerrak. It also emerged that cod larvae from other parts of the North Sea in all the simulated years (2004-2008) aggregate in Skagerrak, and that the aggregation pattern varies among years reflecting the inter-year difference in the dynamics of the water currents. Finally, the study on the growth dynamics (work package E3) showed that the growth of juvenile cod varied systematically among settling areas until the cod attained a length of *c.* 35 cm. This indicates that the juvenile cod do not migrate about in Skagerrak, but tend to stay in their respective settling areas. Provided that these results are valid and that the aggregation pattern of juvenile cod at settling time is known, it should be possible to predict the geographical distribution of juvenile cod a couple of years ahead.

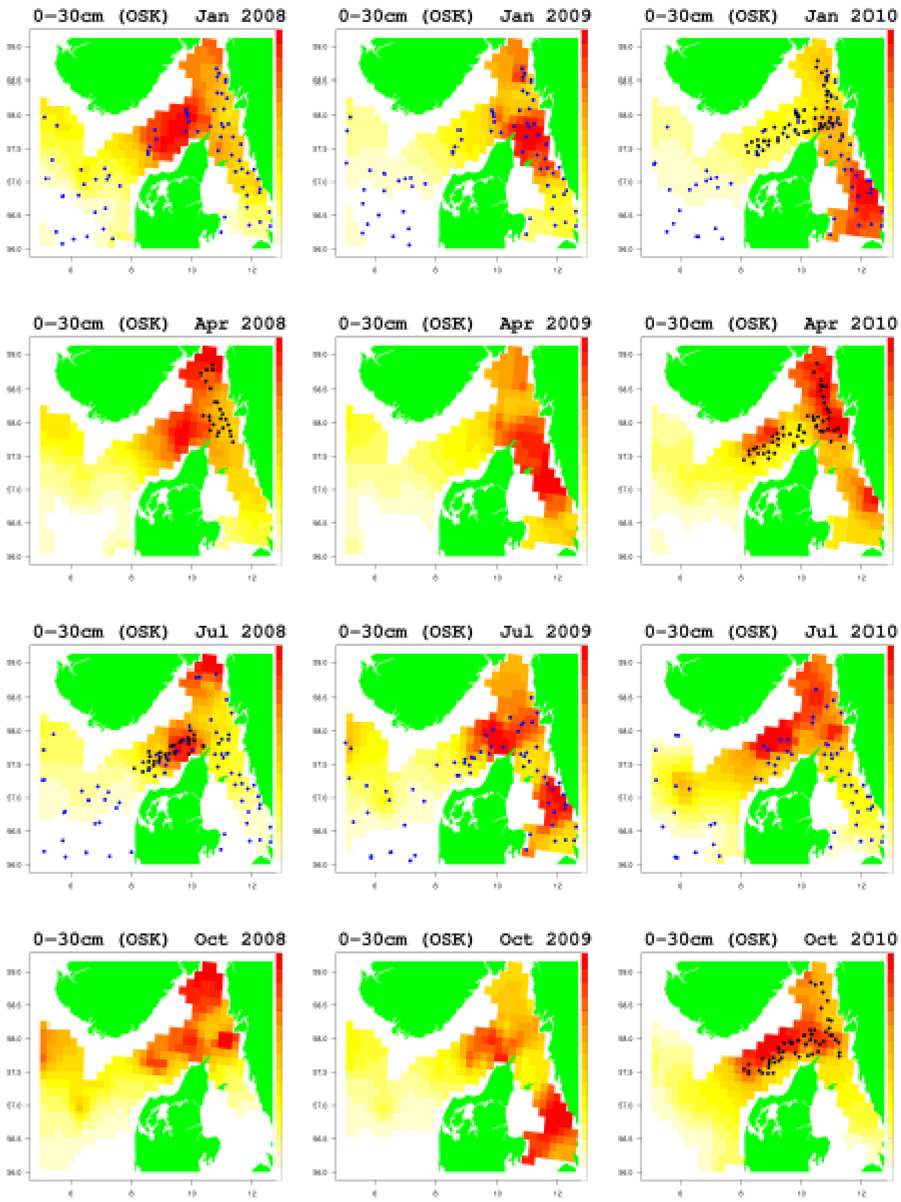


Figure 7. Predictions by the GeoPop model of the geographical distribution in the sea of cod below 30 cm.

The scientific knowledge from, for example, IBTS is not utilized together with the fishermen’s information in any previous analyses of the dynamics of species and size distribution in Skagerrak. Altogether, this means that the challenges taken up by Oskar cannot be solved unless all types of experiences are exploited and systematized in a way so that the knowledge about the geographical distribution of cod can be extracted and quantified. It is important to realize that with regard to RTC matters it is the geographical distribution *in the sea* that is the decisive factor. It is also important that fishermen as well as scientists and managers recognize that the distribution of the populations in the sea is different from the geographical explicit image they see through catch compositions. Development of a new tool is required to extract this information on the population in the sea and to

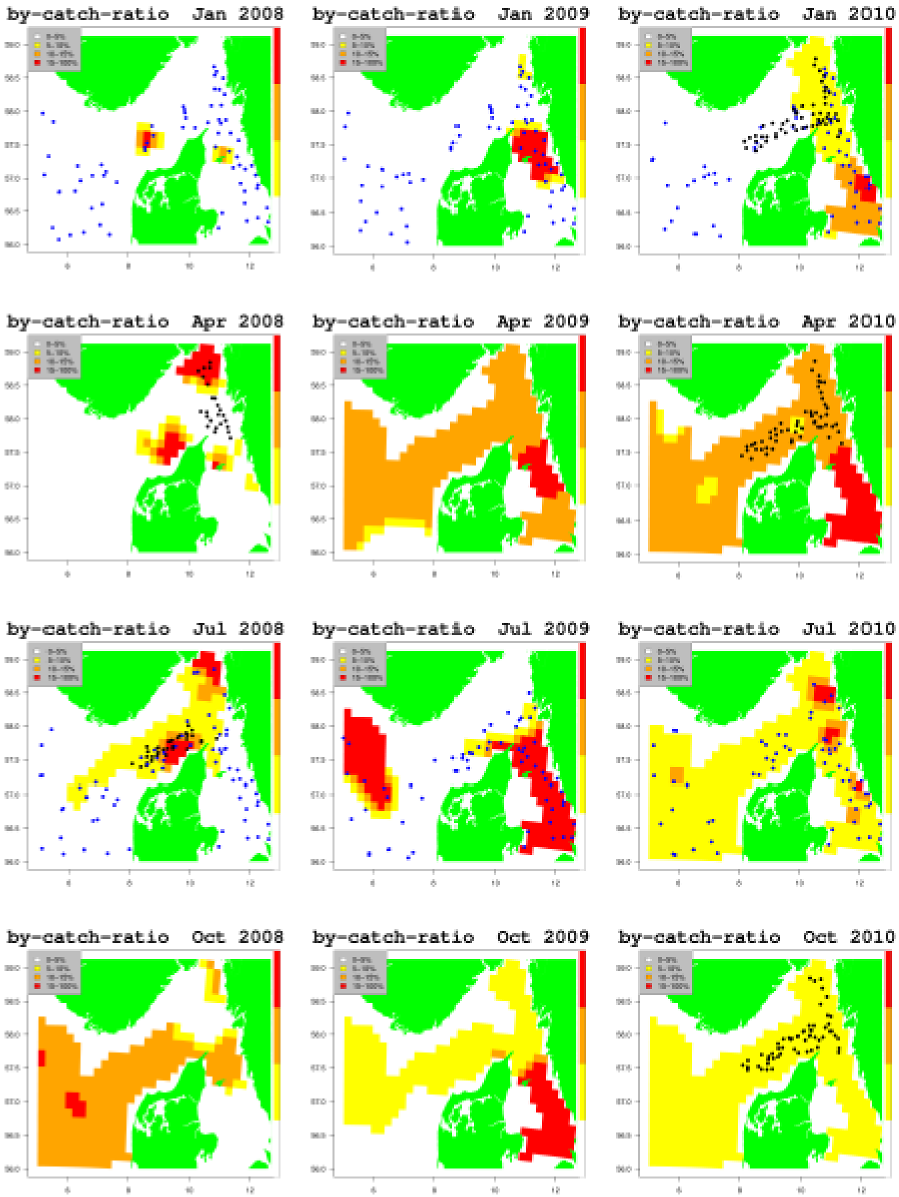


Figure 8. Predictions by the GeoPop model of the geographical distribution of the relative bycatch (percentage of cod below 30 cm relative to total weight of cod in the catch) by use of an OSKAR trawl. The total aggregated catches will have a relative bycatch < 15 % if a large number of hauls are taken outside the red area.

quantify the uncertainties. The GeoPop model is such a tool, and the results show how the distribution of cod in Skagerrak changes in the period 2008-2010 for an arbitrary size of cod. Within this period, it is possible to find areas and times where the different size groups do not overlap geographically, which potentially allows ‘cod avoidance’ strategies based on total selection (and not only the selection of the fishing gear). In its present initial version, the GeoPop model cannot directly be used to predict future changes in the distribution of cod, but the Oskar project shows how it can be done in any succeeding development project. At present, Oskar can only provide relative results for the population, but our work can be used to specify how an up-to-date stock assessment model for the entire sea area can be used as a starting point for a spatially explicit

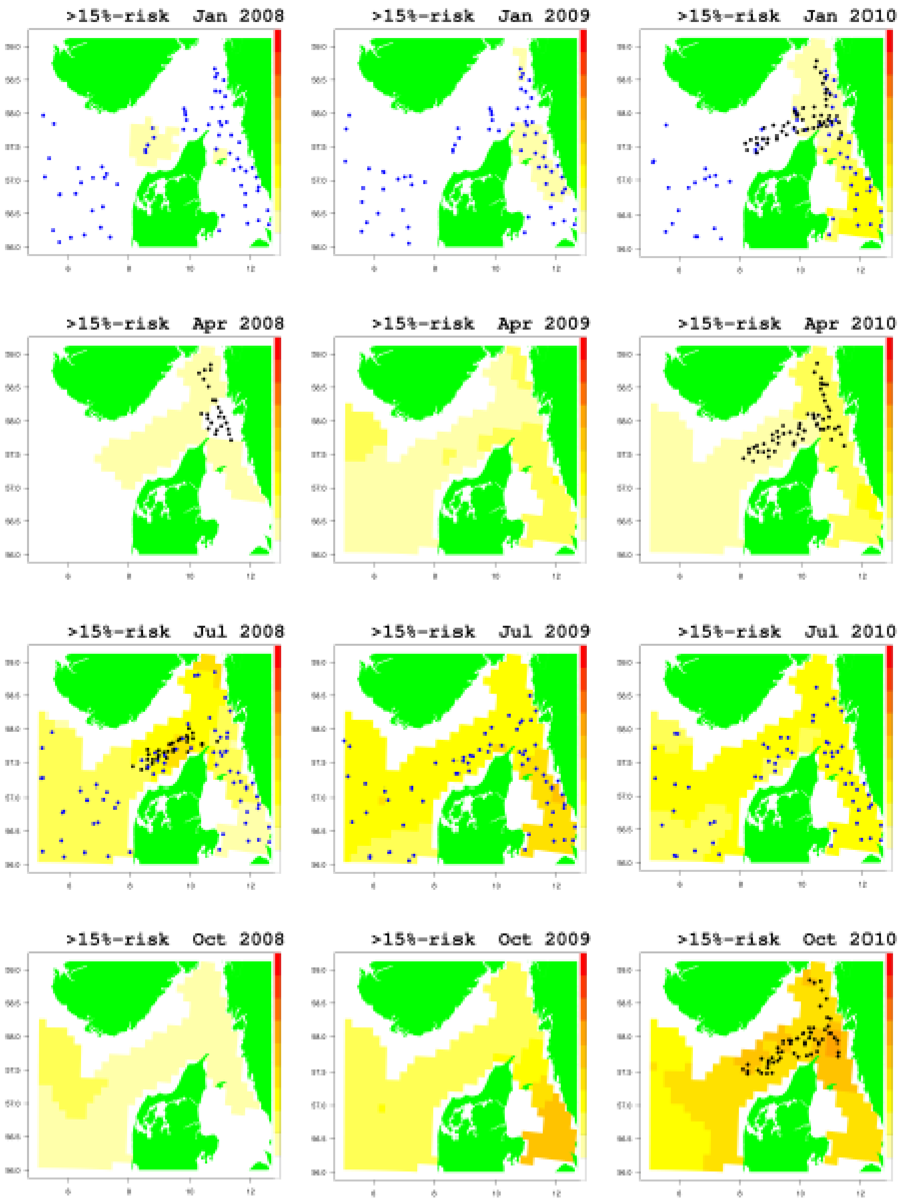


Figure 9. The predictions by the GeoPop model of the geographical variation in the risk of relative bycatches > 15 % by use of an Oskar trawl when accounting for small scale variations in size distribution. The very little contrast is a result of the dominating small scale variability.

model (GeoPop). It should be noticed that all present stock assessment models perceive fish stocks as being homogeneously distributed in the sea and that the approach in the GeoPop model is innovative.

When the GeoPop film based exclusively on Oskar and IBTS survey data shows how the geographical distribution of a size group of cod changes throughout the year, it is not a simple matter to interpret or validate this film. The problem with the validation is that we have used all available survey data to produce the film and no independent data are left for the purpose except for the experience based knowledge of the fishermen. Because the parameter estimation of the GeoPop model is almost independent of a step by step increase of the amount of data (from IBTS to IBTS+Oskar etc.), a first test step might be to run the model exclusively on IBTS data for a prolonged period and then use Oskar data to test the model output. This has not been done in the present project, because it is also necessary to consider the interpretation of the distribution dynamics. When the film shows that the density of a size group of cod are moving from one area in Skagerrak to another in 2008, 2009 or 2010, it may be due to area specific differences in growth, mortality and/or migration rates. The knowledge about these relationships are not included in the present, first version of the GeoPop model, but the initial studies on growth and recruitment of cod demonstrate that at better understanding of these processes is important for the development of a truly predictive tool. Knowledge about area specific population structure (genetics), recruitment potential, foraging and growth together with spawning migrations can be incorporated into the GeoPop model to provide it with the power to produce short term ('Fishery forecasts' for the next week) as well as long term (fishery potential for the coming years) scenario predictions. Another requirement for development of such a tool is the extension of the data material from scientific surveys by inclusion of data on catch, temperature, etc. at haul level obtained from the commercial fisheries. These perspectives constitute the basic idea of the project proposal described below.

Development project proposal (work package G): Integrated fishery and management in the marine ecosystem

The activities in this new monitoring programme proposal are demonstrated by a data flow diagram in Fig. 10. Data from fishermen, scientists and other sources are accumulated in a Marine Data Centre, where the initial processing takes place that ensures the data quality and put the data into standardized formats suitable for storage and exchanges in a data warehouse. Data are used for (1) existing stock assessment analyses, (2) new research on behaviour of marine organisms, population dynamics, species interactions, and ecosystem modelling aiming at improved stock assessment analyses and prognoses, and (3) production of short and long term fishery forecasts (from days to years) with the purpose of easing the fishermen's organization and optimization of their fisheries. In addition, the fishery forecasts can be used to validate the data foundation and models, because the fishermen will be able to check the accuracy of the predictions.

The basic idea of this proposal is to make use of the commercial fleet for comprehensive collection of data on the current condition of the marine ecosystem. The data collection can be performed as an integrated part of the existing fishing operations and reporting of catch data to the authorities. In connection with the implementation of fully documented fishery, the reporting of catch data will anyway be made at the haul level. In addition to the reporting of catch data, the fishermen are receiving scientific monitoring equipment to measure other important variables in the sea. Thus, the expense of data collection is marginal compared to the yield. Further, receiving an appropriate financial compensation, the fishermen may collect data outside their usual fishing location on their way to, from or between these.

The collected information together with data from other sources like scientific surveys, satellites, meteorological and hydrographic models as well as knowledge about the behaviour of marine organisms, are used to develop models that are able to describe the current condition of the ecosystem and forecast the condition at different levels of detail for days or years ahead, including the whereabouts of the fish.

New knowledge on fish behaviour will contribute to innovation within the research area of fisheries technology. Extensive and precise data will minimize the risk of unjustified closures of important areas for the fisheries because of precautionary measures.

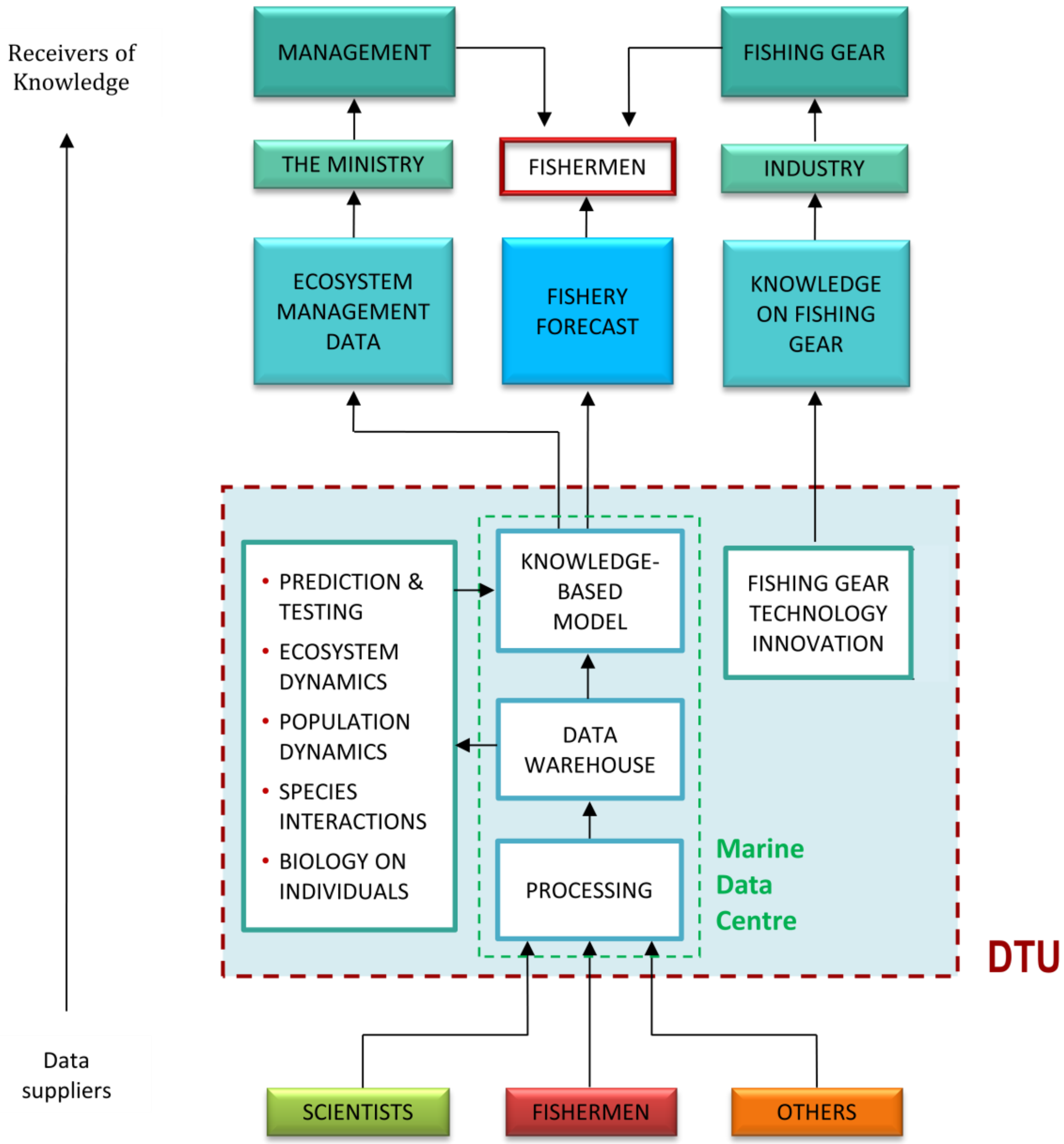


Figure 10. Monitoring programme – Data flow diagram. Establishment of a Marine Data Centre will ensure that large amounts of data obtained from the commercial fisheries are exploited by putting them into standardized formats for storage and exchange in a data warehouse.

Conclusions

Knowledge about the geographic distribution of fish stock during the year will have central importance for all future management plans and -tools. The Oskar project shows how it is possible to utilize the sum of geographic knowledge to optimize the fisheries in Skagerrak and especially avoid unwanted bycatch of cod and unjustified closure of areas. The core of the project is a new geostatistical tool, the GeoPop model, which specifically utilizes different survey data to predict the geographic distribution of all sizes of cod in the sea (the population) during this period. Furthermore GeoPop is able to estimate the variation within the single haul. This small scale variation is considerable, which is also supported by a large variation in almost simultaneous catches of young cod at the neighbouring stations in the Oskar survey. Thus it is scientifically documented that the present criteria for RTC are unjustified, since the young fish are so patchily distributed that the catch in one haul cannot directly be used as proof of the local density.

Furthermore, the results of the Oskar project show how, with a better knowledge about genetics and population structure plus processes like spawning, larval drifts and juvenile growth, it will be possible to predict the distribution of young fish on a larger geographic scale several years into the future and, thus, plan an optimal distribution of fishery and/or use of specifically designed trawl in order to avoid bycatches of fish below trade size. In this connection we/the Oskar project strongly recommends to establish an annual young fish survey to be carried through at the beginning/the end of the year in order to monitor the geographical distribution of 0 to 1 year old fish in Skagerrak. According to the results of Oskar, such a survey will most likely be able to predict the distributions of young fish two years into the future, besides giving a decisive input to GeoPop as a prediction tool. It is also expected to give a significant contribution to an improved stock assessment. Moreover, the genetic composition of young fish sampled from such a survey will contribute substantially not only to a clarification of which stock components of the North Sea/Skagerrak cod that settle and grow up in Skagerrak , but also to validate hypotheses concerning the strength of different spawning areas in the North Sea and the larval drift pattern. At the same time, Skagerrak being a transition area with pronounced depth gradients and frontal zones is an excellent choice to establishing a base line for identification of changes in distribution patterns due to climate changes.

There are no bycatch problems regarding young fish in the gillnet fishery, but otherwise there is, not surprisingly, need for better data coverage in order to implement optimal selective/targeted fisheries in Skagerrak. In the Oskar project, it has only been possible to carry out quarter 3 survey in 2008 and survey in the other three quarters in 2010. Year to year variations in the physical and biological conditions produce distribution patterns, which deviate from the average and thus also from the general picture of fish distributions represented by the fishermen's experience based knowledge. As an example we are not today fully able to understand the importance of the cold winters in 2009 and 2010 in relation to 2008. These conditions lead to clear conclusions as to how Oskar must be continued:

It is necessary to utilize the collected interdisciplinary knowledge about the dynamics of the geographical distribution patterns of species and fish within years and in between years. The apparently simple questions ”Where are the fish and why?” are complex when the management demands knowledge on such a small scale in space and time that a single trawl haul represents. In the future there is a need for further integration of a joint survey/monitoring effort with the collection and analysis of process knowledge – a joint data collection which optimally should continue into a further development of the dialogue based collaboration between scientists and fishermen. The Oskar project constitutes the first step towards linking seven sources of data and information: The fishermen's experience based knowledge, logbooks and VMS-positioning information, geographical distribution of the species composition in catches from discard trips, trawl selection and selective trawls, catch data from minimal season monitoring (four Oskar surveys), scientists' monitoring knowledge through the International Bottom Trawl Survey (IBTS) and process based knowledge (genetics and population structure, spatially explicit recruitment and growth dynamics etc.).

The GeoPop model presents a great potential for continuing the process of linking data and knowledge. Beside the important question on the population structure of cod, these issues concern model validation, expanding the model to all life-histories from eggs and larvae to adult fish and the development of modified versions for spatial stock assessment. There may also be a need for expanding the model with a depth dimension, day-night variations in distribution patterns and spatial overlap with competing species or food organisms. Some of these issues will be elucidated as part of concluding the sister project RESOURCE for North Sea cod in 2012.

Although the GeoPop model is useful to ”fill in holes in data in space and time” there is a special need to be able to extend the collection of data on scientific cruises with a far better utilization of real time data from the commercial fishery. It could be implemented with a Marine Data Centre as illustrated in Fig. 10, especially if the programme for fully documented fishery is expanded to sensor based fishery, so for instance temperature routinely is measured on the trawl.

Acknowledgements

The project was funded by The Danish Ministry for Food, Agriculture and Fisheries, The European Fisheries Fund and DTU Aqua. We would like to thank Kurt Madsen from Danish Fishermen's Producers' Organization for initiating the project on behalf of the Danish Fishermen Association (DF), Claus H. Pedersen, Jan Hansen and Henrik S. Lund from DF for their engagement in this cooperative project. Also thanks to the vessel owners Jesper Nielsen, Jens Poulsen and John Jacobsen and their crew onboard the Danish fishing vessels HG-350 *Luna*, FN-234 *Canopus*, and S-544 *Dortigi* for their collaboration throughout the project. Finally we would like to thank all the DTU staff involved in the project, especially Henrik Mosegaard for ideas and constructive input throughout the project and Jan Pedersen, Søren L. Grønby, Per Christensen and Hans J. Olesen for making the surveys possible.

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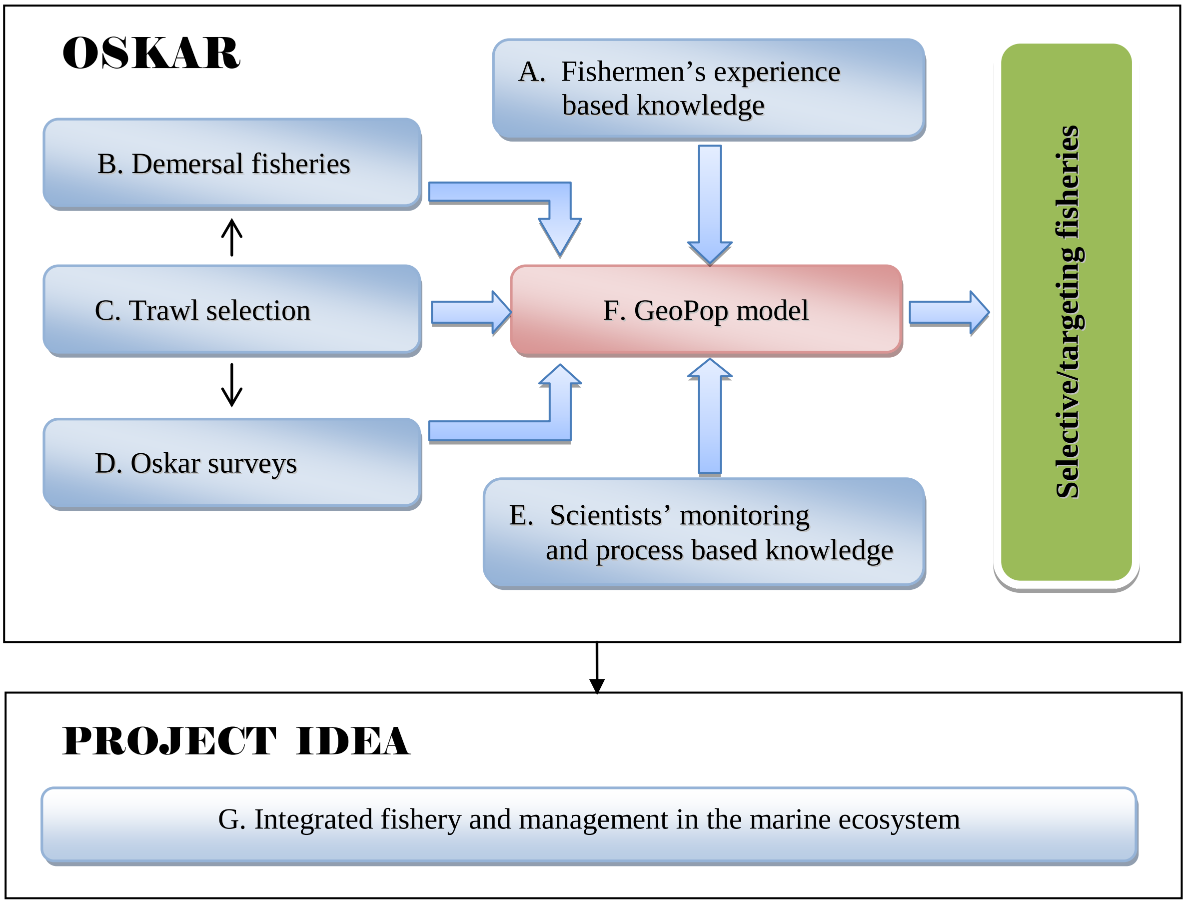
Work Packages A – G



The work packages and their interrelationships

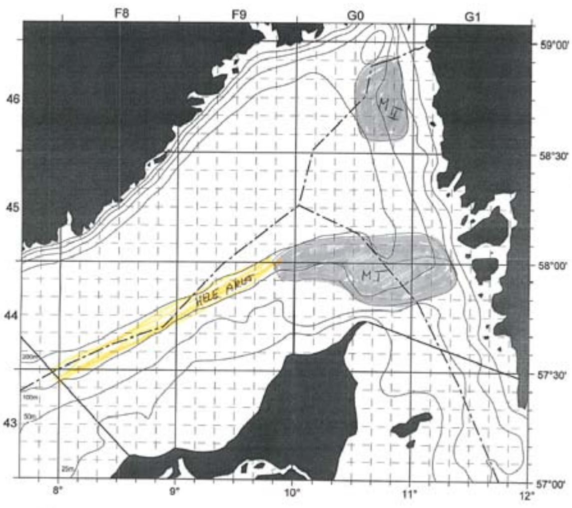
Work package A

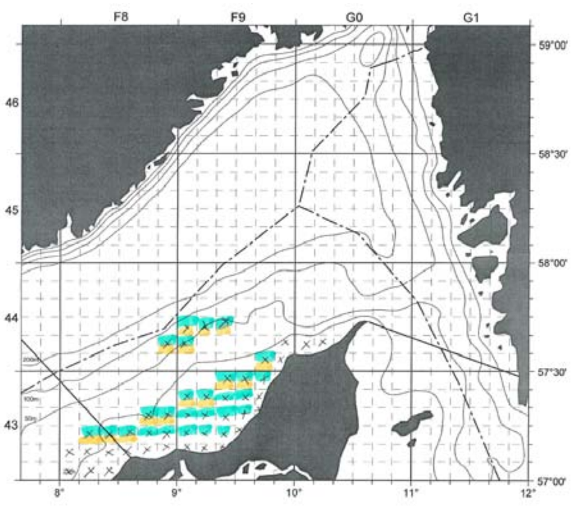
Fishermen's experience based knowledge

Geographical distribution of commercially important species

by Maria F. Pedersen

Experience based information from Jens Poulsen, Jesper Nielsen, John Jacobsen and Claus H. Pedersen





Method

An important part of the Oskar project is the collaboration between scientists and fishermen. Fishermen have the everyday hands on and knowledge about what is happening at sea whereas scientists often have to rely on semi-annual surveys. A way to collect some of the fishermen's knowledge is through mapping of their experience based knowledge about where to go and fish the species cod, haddock, saithe, plaice and Norway lobster. Their knowledge is biased by their fishing method and gear selectivity, and generally gives no information about undersized fish.

As a part of two fishermen/scientist workshops, the fishermen were asked to specify where and when they would catch cod, haddock, saithe, plaice and Norway lobster in Skagerrak and also to put down notes if any special conditions would change or drive their decisions. The gillnetter only focused on cod, plaice and hake.

Hand drawn maps and additional information were transformed into ArcMap layers making them comparable with survey data and other mapped information. Generally, the geographical information is shown by quarter. The exception is cod for which detailed information allows monthly distribution maps.

Cod is the only species that is mapped alone. In order to recognize potential conflict areas with regard to cod avoidance, cod is included in the maps of the other species (Figs 2-7).

Cod

According to the fishermen, there are areas in which cod can be caught throughout the year. The trawlers have two locations, one spot in the north-eastern part of Skagerrak at depths between 100 and 200 m and one close to the North Sea border at depths between 100 and 150 m (mainly when 'the current is running'), whereas the gillnetters find cod throughout the year around the reefs in square 44F9 (Fig. 1a&b).

The trawlers see the same pattern of cod distribution from October to March. In addition to the permanent locations, they find good catches in an area called "Renden" just north-west of Skagen in square 44G0, and they see a lot of juvenile cod in a strip from the North Sea border all the way to the tip of Skagen at depths between 70 and 90 fth (Fig. 1a&b A-C; J-L).

From April to September, the area around the reef is a god catch area, but exact locations vary according to the conditions. From April to June the best location in this area is north of the reef during a north-western gale, whereas the good spot are located east of the reef from July to September at depths between 25 and 45 fth (Fig. 1a&b D-I).

In April, May and June, during calm weather at dusk and dawn, cod can be caught at "Takkerne" located just outside the harbor of Hirtshals in square 44F9 (Fig. 1a. D-F).

In May and June, two larger areas are located north of Skagen at depths of 100-200 m (Fig. 1a E, F).

In June, August and September there is a saying "if there is sandeel in the gravel, there is cod on the Rough" which is located in square 43F8 (Fig. 1b. F, H, I).

The gillnetters generally follow the outward migration of cod from the shallow (<25 m) water in "Jammerbugten" during January and February, towards an area at depths between 25 and 50 m in which they are caught from April to June. Later in the year, they are not available for the gillnetters until October, where they start their inward migration towards shallow water (Fig. 1a&b).

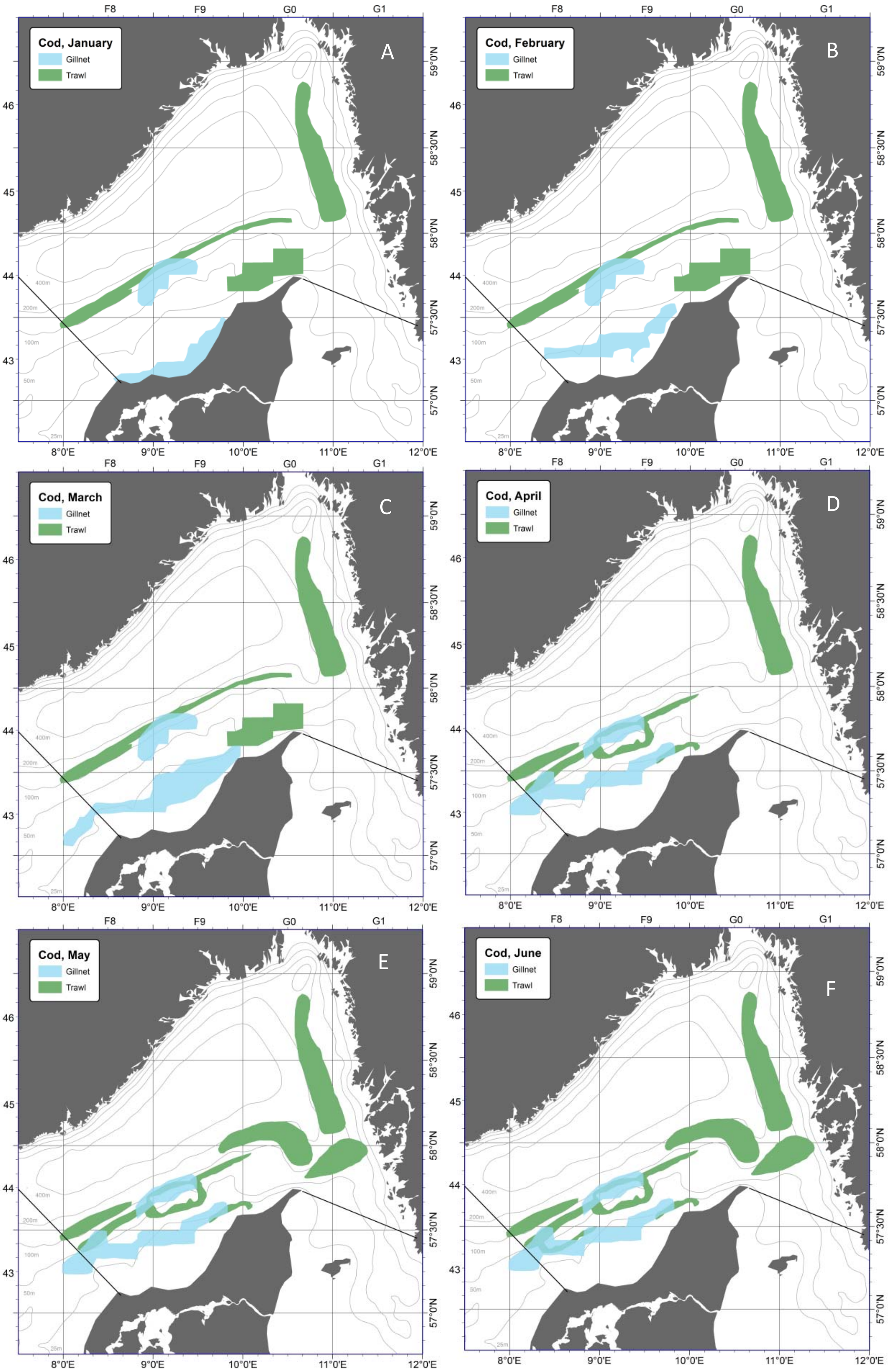


Figure 1a (A-F). The fishermen's experience based knowledge on the distribution of Atlantic cod in Skagerrak (January-June). Gillnetter: blue; trawlers: green.

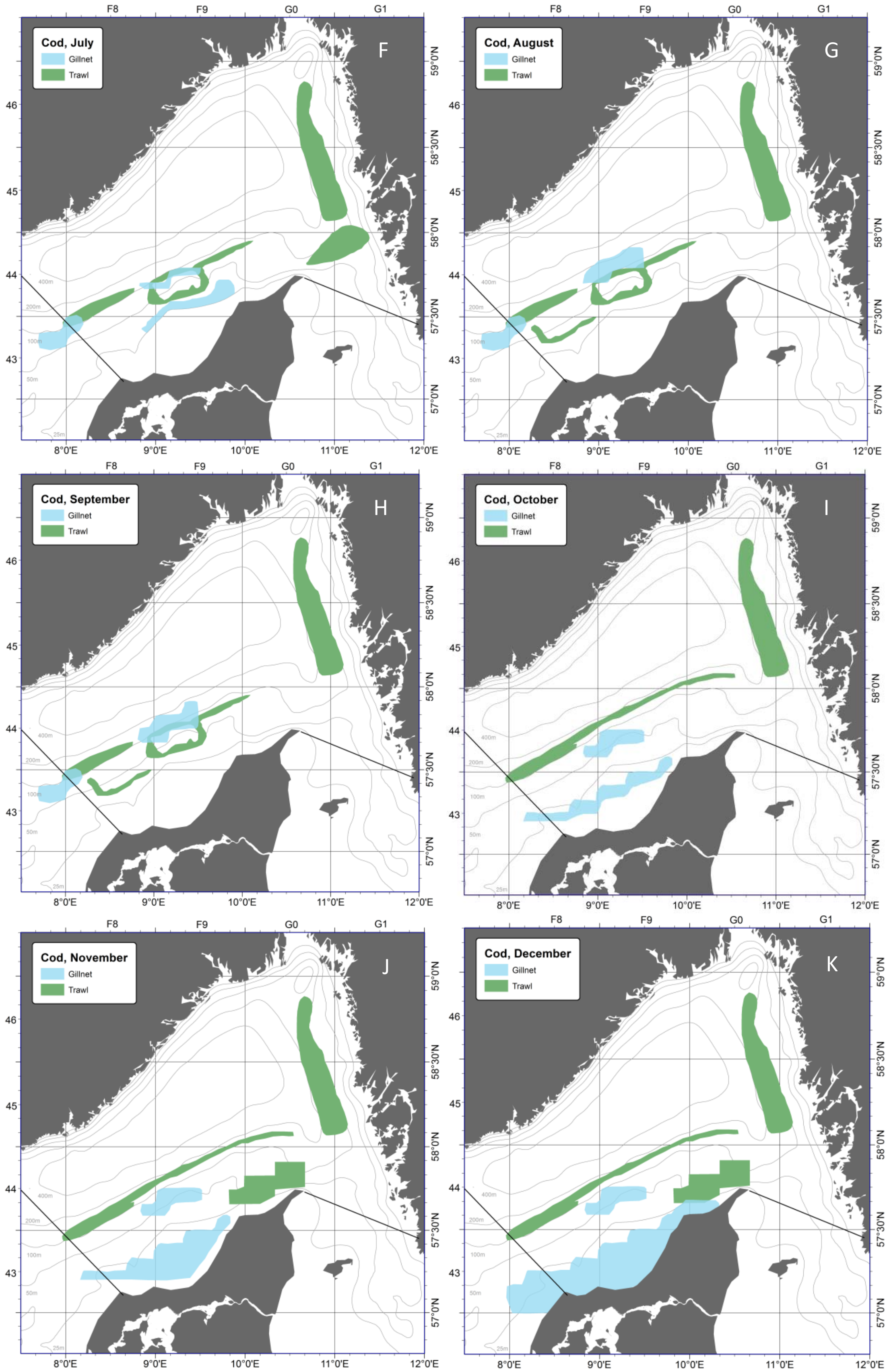


Figure 1b (F-K). The fishermen's experience based knowledge on the distribution of Atlantic cod in Skagerrak (July-December). Gillnetter: blue; trawlers: green.

Haddock and cod

According to the fishermen, haddock are present in four areas throughout the year (Fig. 2). The largest area (1) is north/northwest of Skagen mainly in square 44G0. A smaller area (2) is located just north-east of the reef between 150 and 200 m of water, and just south of this area an even smaller area (3) at 50 and 100 m. The last area is a strip close to the North Sea border at 100-150 m, identical to the year around cod area (4).

During the 1st and 4th quarter (November to February) there is also a location (5) just south-west of the reef at around 75 m (Fig. 2A, D). In addition, in the 3rd quarter (July), there is an area (6) just west of "Grenen" at 25-50 m (Fig. 2C).

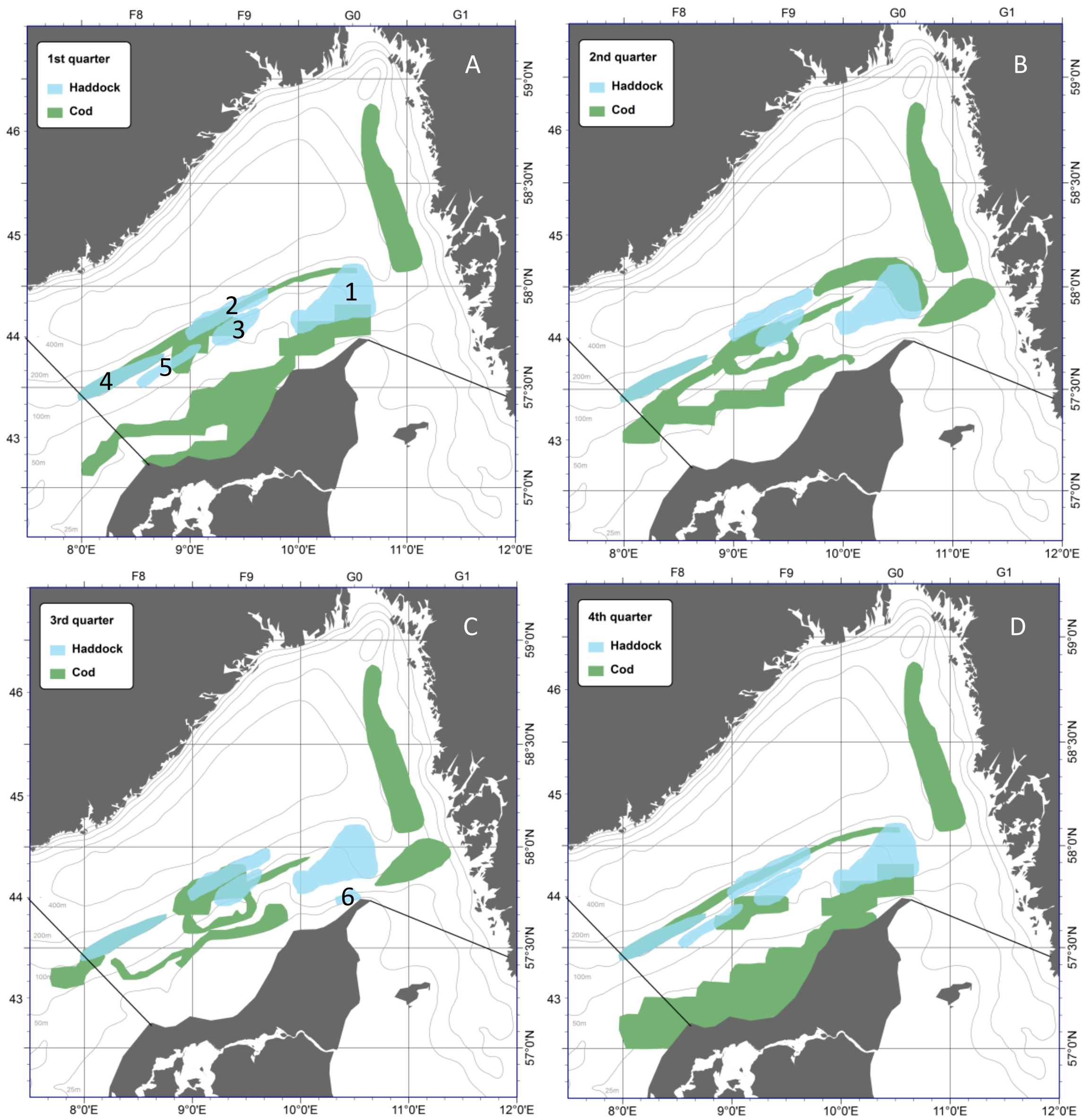


Figure 2. The fishermen's experience based knowledge on the distribution of haddock (blue) and cod (green) in Skagerrak by quarter of the year. (Numbers 1-6 in the figures refers to the identified haddock areas)

Area 4 next to the North Sea border is identical to a cod area and, therefore, a potential cod conflict area all year round. During the 1st and 4th quarter, the main conflict area according to the map (Fig. 2 A,D) is just north-east of the reef (area 2), which is actually is the area populated by many small cod from October to March. The other haddock spots around the reef are exclusively located in gillnet areas and therefore not a conflct area for the trawlers.

In the 2nd quarter, a possible conflict area is located just north of Skagen where area 1 partly overlap a cod area in May and June, and another north-east of the "Reef" where part of area 3 is a good location for cod and other roundfish, especially at windy conditions (Fig. 2B). In the 3rd quarter, area 3 overlaps the "Reef" and east of the reef where trawlers potentially catch many cod. Area 2 on the other hand overlap the cod area for gillnetters and is therfore not considered a conflict area (Fig. 2 C).

Saithe and cod

According to the fishermen, saithe are mainly present in the same areas throughout the year. The highest concentrations are found at depths between 70 and 90 fth, from the North Sea border to the coast of Sweden. In the 3rd quarter (August and September) smaller saithe can be caught in the northern part of Skagerrak in square 46G0 (Fig. 3). In the 1st and 4th quarter, there is a potential cod conflict area in the strip north of the "Reef" where the trawlers observe small cod (Fig. 3 A, D). In the 2nd quarter (May and June) there is an overlap with the two areas north of "Grenen" as well as close to the North Sea border (Fig. 3 B). In the 3rd quarter (July), there is still an overlap with the eastern area north of "Grenen", whereas there in August and September may be an overlapping area with cod in the northern part of Skagerrak (Fig. 3C).

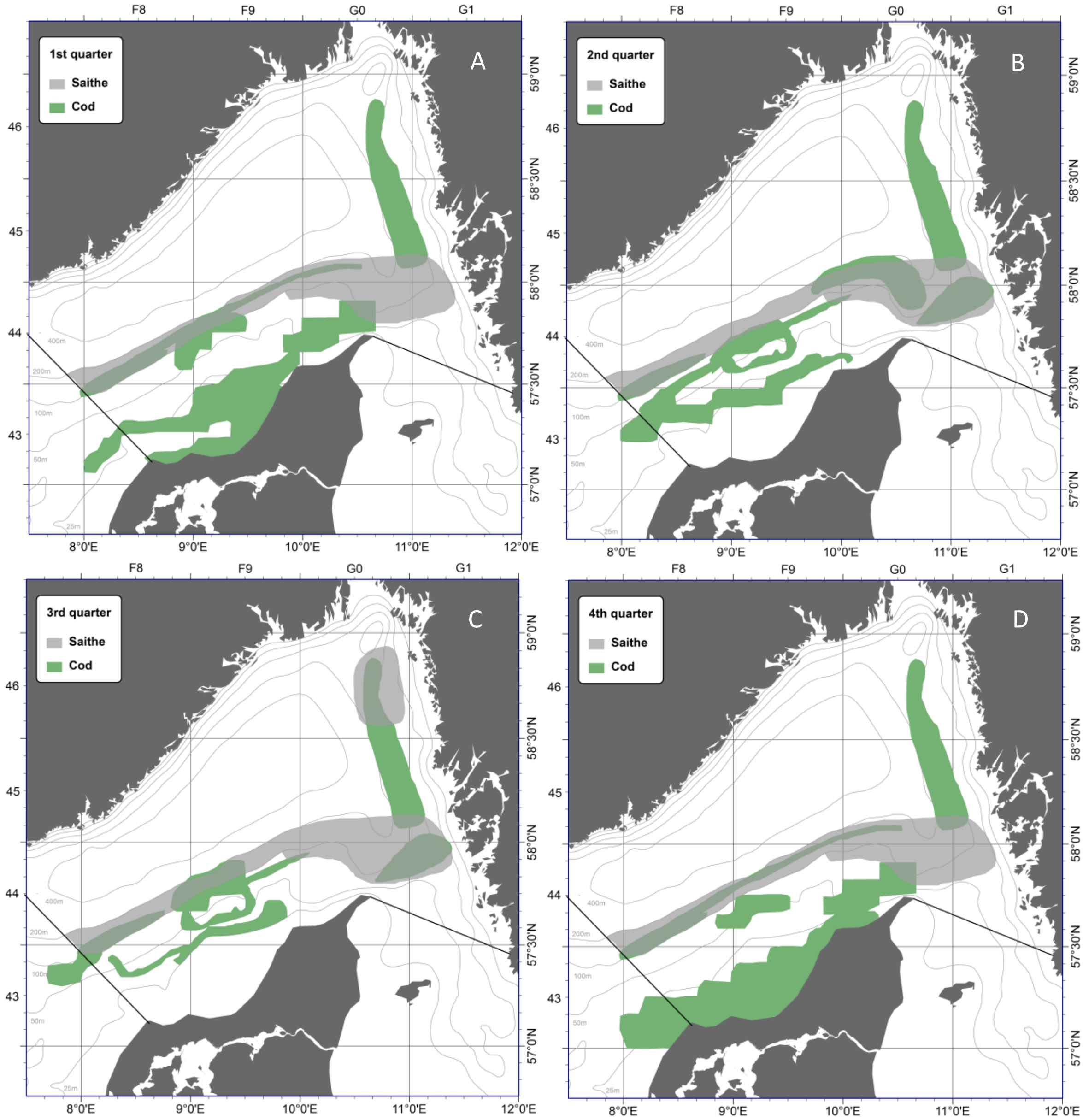


Figure 3. The fishermen's experience based knowledge on the distribution of saithe (grey) and cod (green) in Skagerrak by quarter of the year.

Plaice and cod

Plaice is mainly distributed southwest of "Grenen" (Fig. 4). There is a small location just on the top of "Grenen" where they can be found all year round, but the best time for plaice fishing at this location is, however, during calm conditions in February and March. A large area covering "Jammerbugten" up to around 50 m is a good area for plaice trawling from June to October. The gillnetters, however, follow the plaice outwards during the year, starting in March and April close to the coast, at shallow water. From May to July they catch them in two areas, just north of the March April area and just around the reef at depths around 100 m.

The overlapping areas for cod and plaice are very limited. In the 1st quarter, the map seemingly shows a conflict area in “Jammerbugten”, but is not real as the cod is there in January whereas the plaice don’t get there until March. In the 2nd quarter, the trawlers have a conflict area around “Takkerne” between 25 and 50 m just north of “Jammerbugten” and south of the “Reef”. In the 3rd quarter, the potential conflict areas is also more limited than at first sight on the map (Fig. 4 C) as the gillnetter catch plaice at the reef in July and cod in the same area in august. It’s more or less the same in 4th quarter as the presence of cod close to the coast is what the gillnetters observe whereas the plaice in “Jammerbugten” is what the trawlers see.

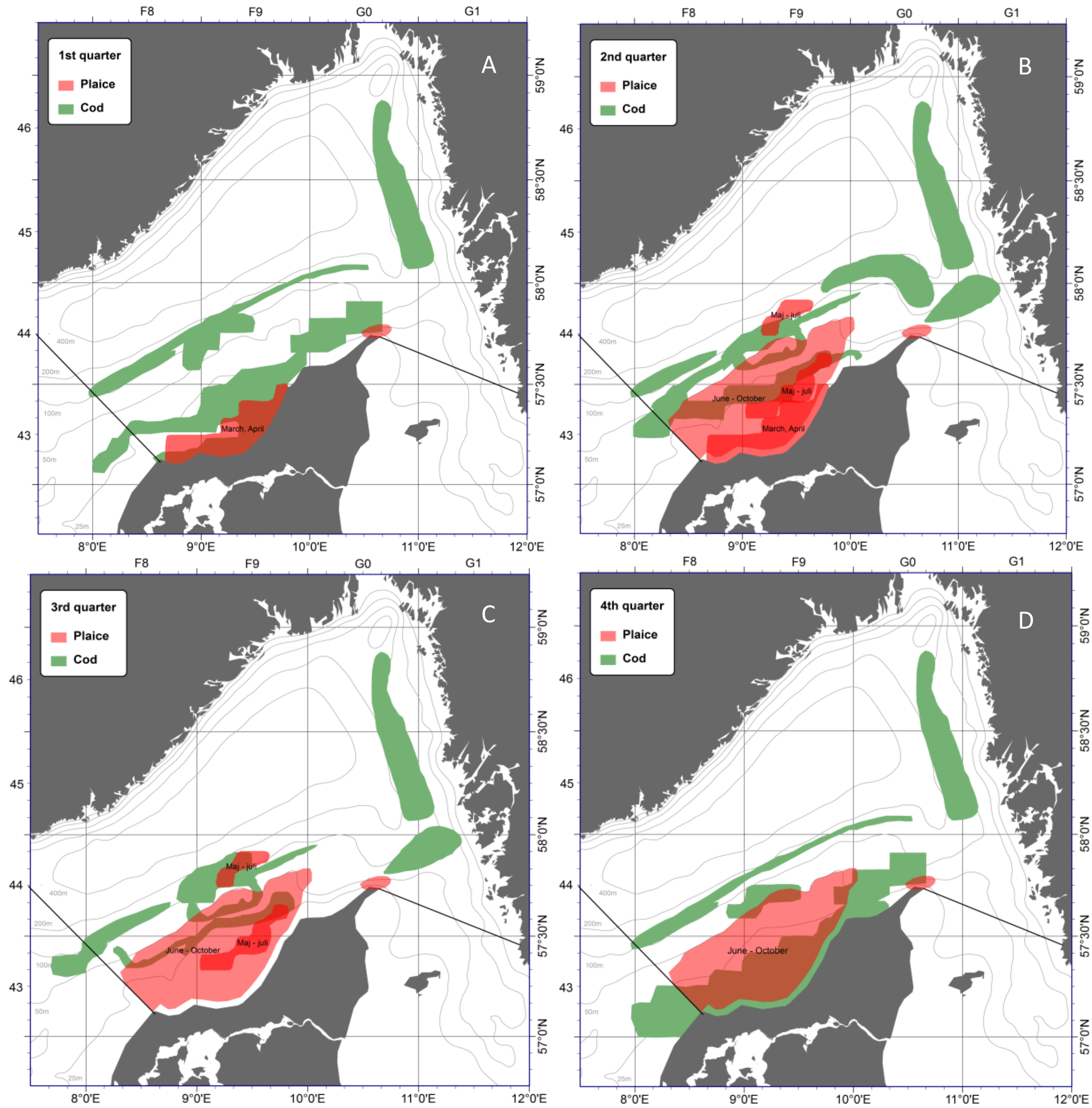


Figure 4. The fishermen’s experience based knowledge on the distribution of plaice (red) and cod (green) in Skagerrak by quarter of the year.

Hake and cod

The experience based knowledge on hake is limited to the gillnetters' information as the trawlers usually don't have substantial catches of this species in Skagerrak (Fig. 5).

There is no information on the whereabouts of hake in the 1st quarter, but they are known to stay at deep water during the winter. It is not until the 2nd quarter around June that the gillnetters catch hake (Fig. 5B). Here they are found from around 25 m to more shallow water in "Jammerbugten" until the end of July. In the 3rd and 4th quarters (August to October) they can be caught around the "Reef" at a depth of around 100 meters (Fig. 5C,D). It is also here that the highest risk of a conflict area is found in August.

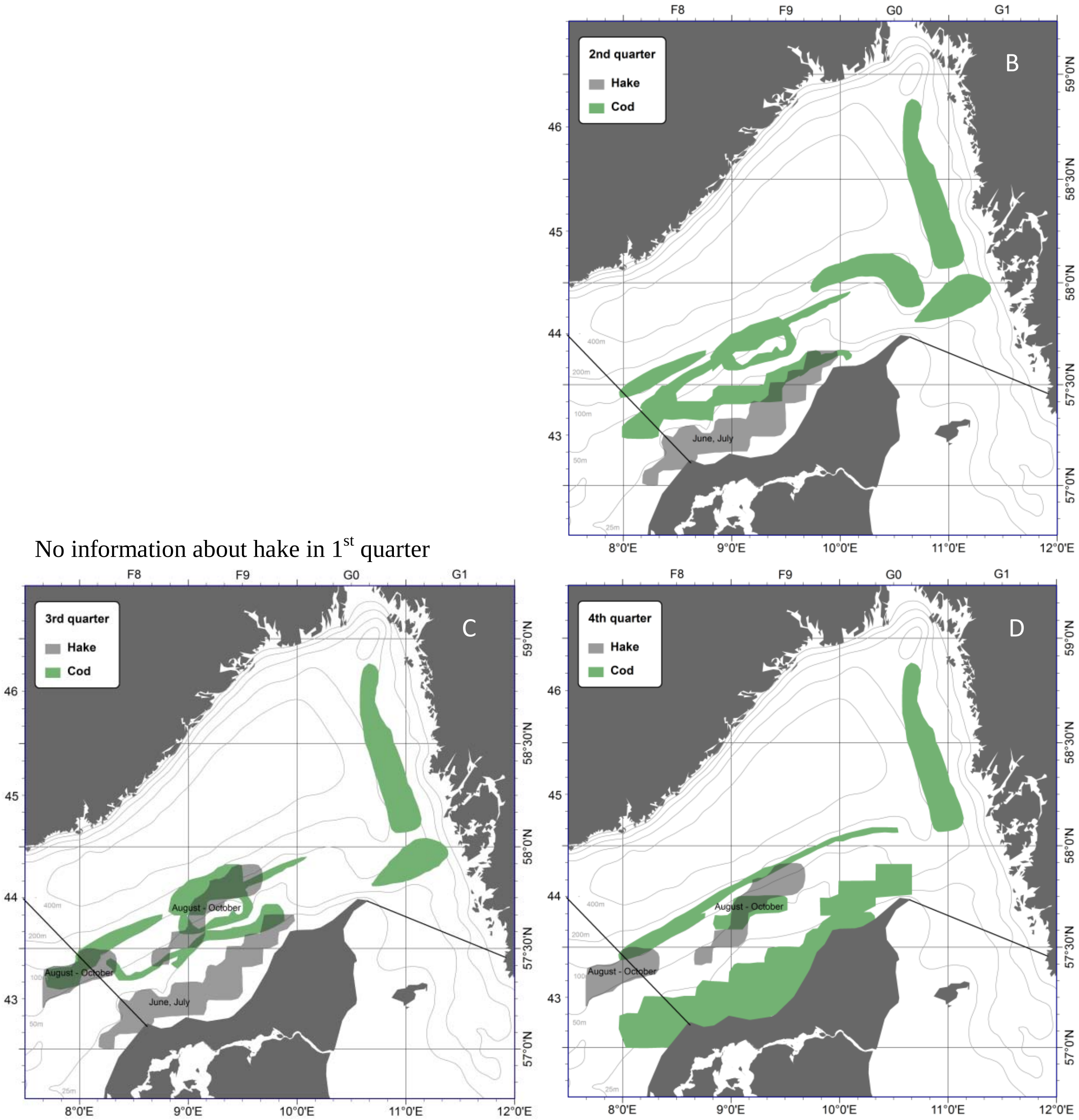


Figure 5. The gillnetter's experience based knowledge on the distribution of hake (grey) and cod (green) in Skagerrak in the last three quarters of the year. He had no information about the first quarter.

Norway Lobster

Norway lobster is not caught by gillnetters. The experience based knowledge is therefore only based on information from the trawlers. At a first glance at the maps (Fig. 6), it seems like there is an all year fishery after Norway lobster in the north-western part of Skagerrak. This is because trawling is going on here in spring and fall and therefore illustrated in all quarters.

The Norway lobster season starts in the spring, but a small fishery is conducted in January just west of “Grenen”. In March and April, the fishery is located around depths of 200 m, and sometimes in the spring in an area at 50-60 fth (Fig. 6 A,B). In the 2nd quarter (May), the night fishery located close to the border of/and in Kattegat starts and continues until September. West of the area a strip at depths between 23 and 45 fth is used for day fishing of Norway lobster from May to June and again in August and September. In November, the area located at 50-60 fth just north of “Grenen” are fished.

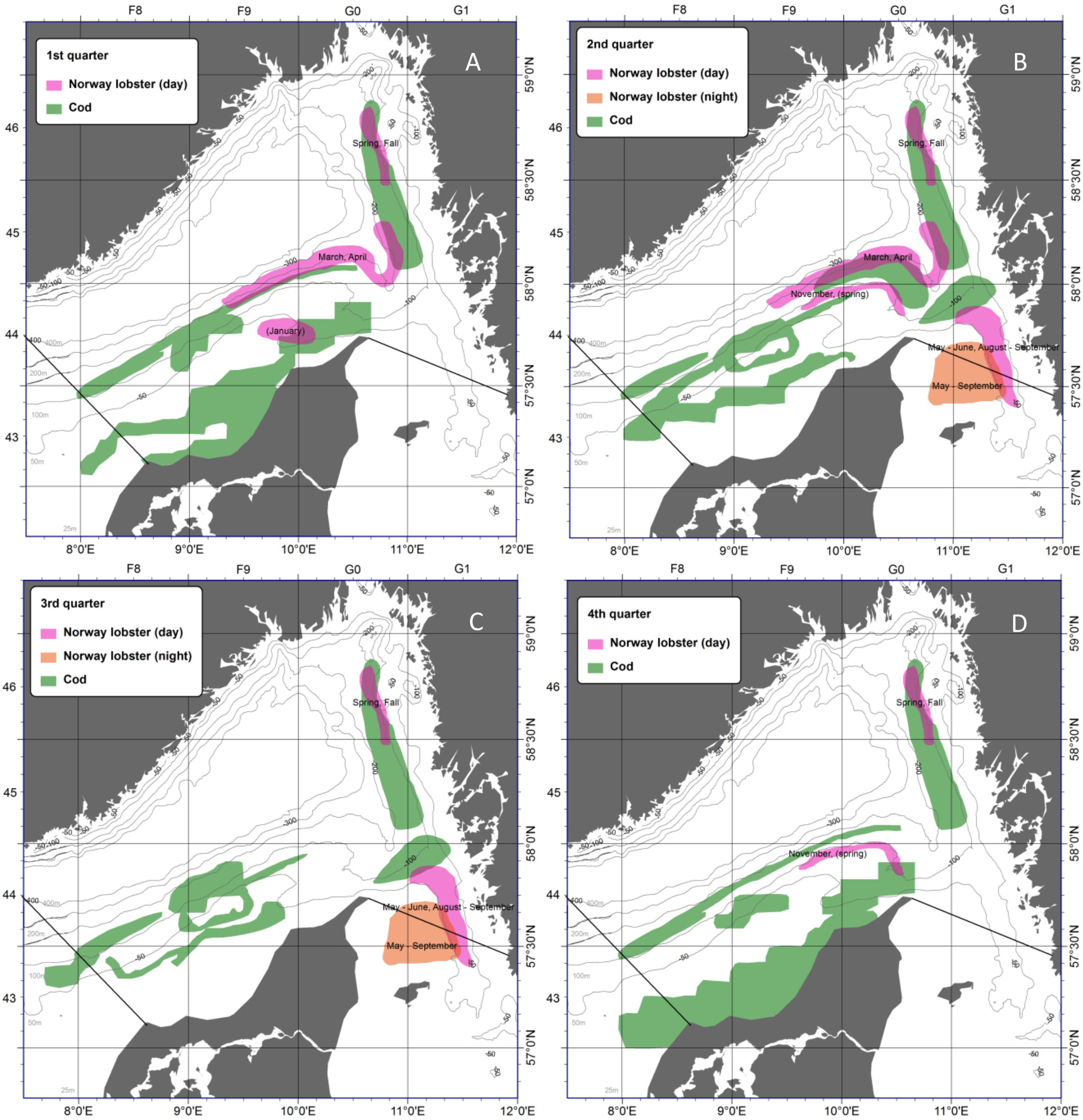


Figure 6. The fishermen’s experience based knowledge on the distribution of Norway lobster (day: pink; night: orange) and cod (green) in Skagerrak by quarter of the year.

According to the maps, the main conflict area between cod and Norway lobster is found in the 1st quarter, where the March, April Norway lobster patch overlaps the cod strip with many smaller cod between 70 and 90 fth, and in the northwestern area in the spring and fall.

Witch flounder, young fish and cod

Witchflounders are generally caught all over Skagerrak as a welcomed by-catch in the trawl fishery (Fig. 7A) There is not any difference between seasons in the distribution, but there is a year round distrubution according to size. The large individuals are close to the Norwegian coast, the small indivuals are towards the Swedish coast and the medium size witch flounders are usually caught just north-east of "revet".

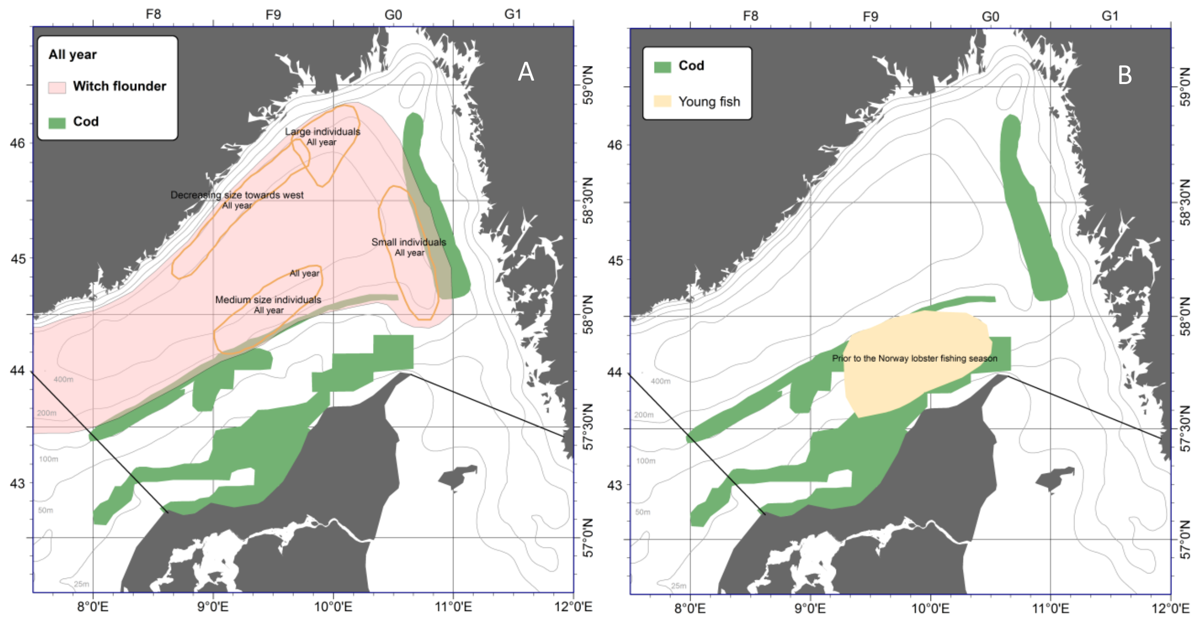


Figure 7. Left:The general distribution by size of witch flounder according to the fishermens experience based knowledge. Right: The only general experience based knowledge about the distribution of young fish.

The fishermen did not have much knowledge about the wherabouts of juvenile cod and other young fish. Only an area north-west of "Grenen" (Fig. 7 B) could be identified as an area, where they observe small gadoids, but only for a while at the start of the Norway lobster fishery.

Work package B

The demersal fisheries

by Bo S. Andersen

General introduction to the demersal fishing fleet in Skagerrak

The demersal fisheries (using mesh sizes ≥ 90 mm) in Skagerrak constitute one of the major parts of the fisheries in Denmark with an annual landing value of app. 300 mill. DKK (Fig. 1). Besides demersal fisheries, specialised fisheries for prawns (semi pelagic 34-36 mm mesh size) and small pelagic species (<33 mm, targeting mainly herring and industrial species) also take place in Skagerrak. However, these fisheries are in general highly specialised in their targeting behaviour with a relatively small amount of by-catches of demersal fishes.

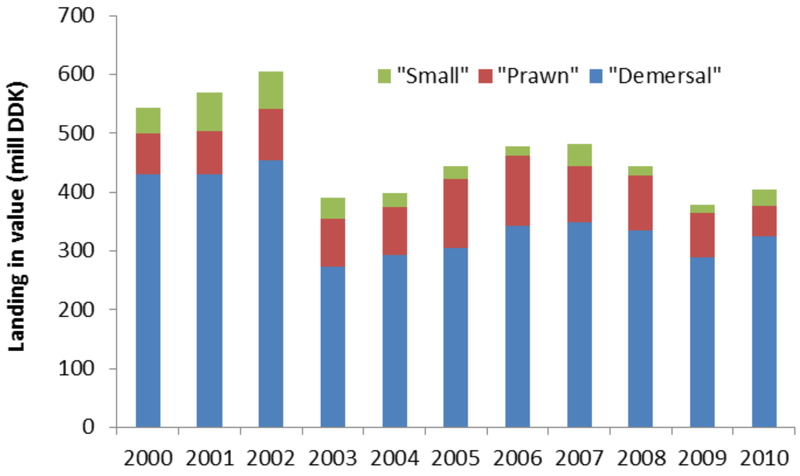


Figure 1. Total landings by mesh size group in Skagerrak from 2000 to 2010. "Small":<33mm mesh size (mainly industrial and small pelagic species); "Prawn": 33-69mm mesh size (mainly prawn landings); "Demersal": >=70mm mesh size (represents mainly all commercial demersal species). All data are extracted from the DTU Aqua fisheries database (DFAD).

The demersal fisheries in Skagerrak are characterised by targeting a broad range of fish and crustacean stocks, where the main economic species Nephrops, cod, plaice and saithe contribute to app. 70 % of the total landing value (Fig. 2 and Appendix 1). Furthermore, a large number of demersal species may also have a key economic role for the demersal fishing vessels fishing in Skagerrak. The commercial fishing vessels participating in the demersal fisheries in Skagerrak can be divided into three fleet segments based on main gear used in a given year (in terms of revenue): a trawler fleet, a gillnet fleet and a Danish seine fleet. Determining the vessels to be included in the fleet analysis, the annual revenue is set to be above the minimum threshold level that defines a fulltime commercial fishing vessel. The economic threshold level is set each year in the annual fisheries economic report made by the Institute of Food and Resource Economics (FOI). Vessels above the FOI economy minimum criteria contribute to app. 93 % of the total demersal landings in Skagerrak.

In 2010, the demersal fleet in Skagerrak consisted of 223 active vessels, being reduced by more than 50% during the past decade (Fig. 4). It is dominated by the trawler fleet in terms of numbers of vessels and kilowatt days as well as landing value (Fig. 3). The *Nephrops* and saithe stocks are exclusive landed by the trawler fleet, whereas the cod landings are more equally distributed among all three fleet segments (with a slight dominance of landings from the Trawlers fleet). The plaice stock is mainly landed by the Danish seiners and to a lesser extent by the Trawler fleet.

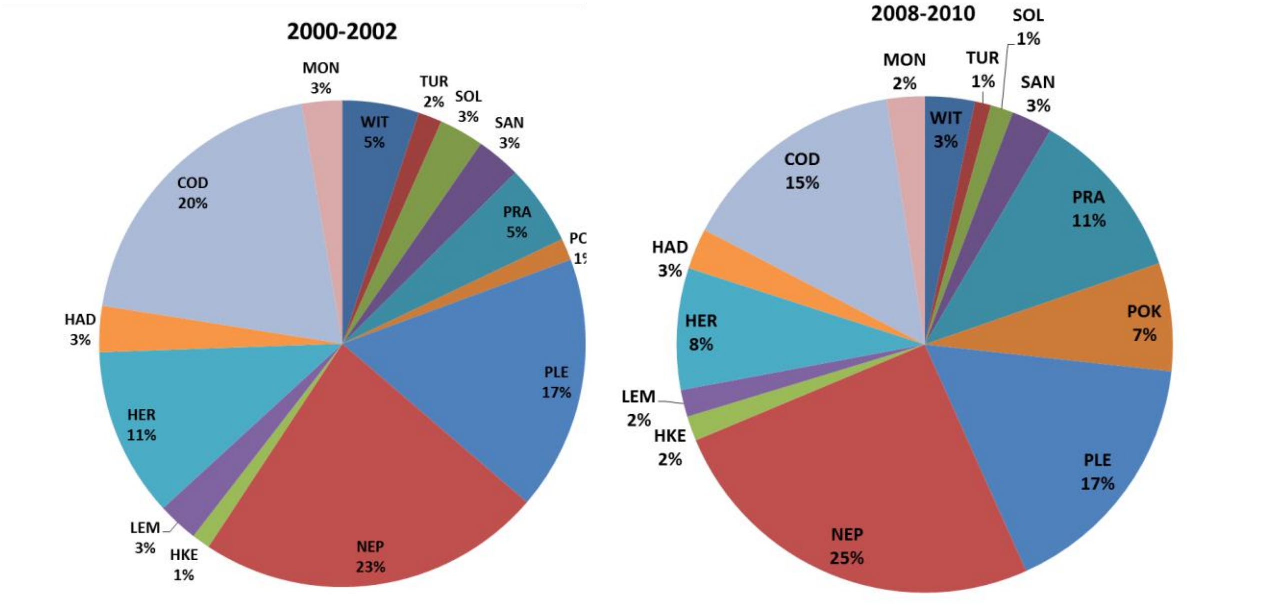


Figure 2. The landing value of the main species in Skagerrak in the periods 2000-2002 and 2008-2010. Data are extracted from the DFAD database. Species code: WIT=witch flounder; TUR=turbot; SOL=sole; SAN=sand eel; PRA=prawn; POK=saithe; PLE=plaice; NEP=Nephrops; HKE=hake; LEM=lemon sole; HER=herring; HAD=haddock; COD=cod; MON=monk fish; POL=pollack; MAC= mackerel

The fishing activity (on a yearly basis) of individual fishing vessels in Skagerrak highly varies from only a few days to fishing exclusive in Skagerrak (Fig. 5). However, the vessels having their main fishing effort in Skagerrak also contribute to the majority of the landing of the most economic important species (Fig. 6). These vessels have their basis harbour either within Skagerrak or close to the boarder of Skagerrak in either North-Jutland [Strandby (FN), Hirtshals (HG) and Skagen (S)] or Northwest Jutland [Thyborøn (L) and Hvidesande (RI)].

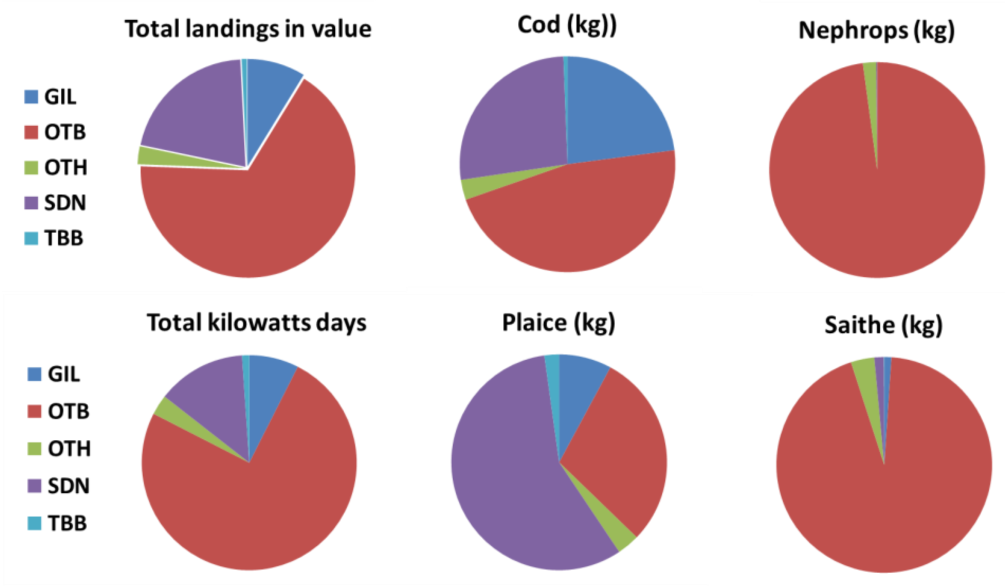
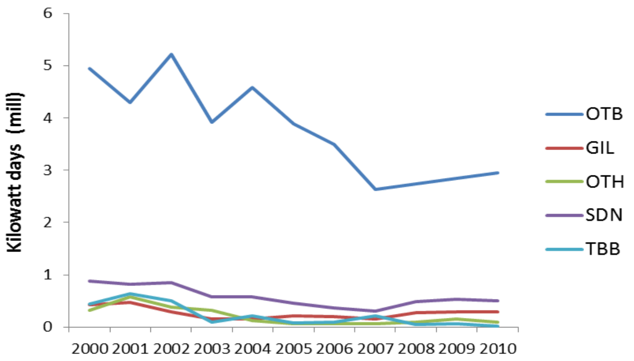


Figure 3. Demersal landings by main fleet groups in Skagerrak (2008-2010).

The demersal fleet in Skagerrak has undergone dramatic changes during the last decades. Particularly from 2000 to 2006, large decline was observed in both number of vessels and kilowatt days (Fig. 4 & 7). These changes was primarily explained by the decline in the cod stock in the end of the nineties and subsequently resulted in significant restriction of the TAC for cod in the



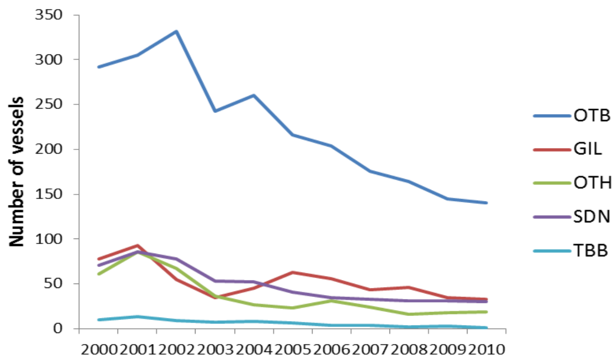


Figure 4. Development in kilowatt days (left) and number of active fishing vessels in Skagerrak (right) in the period 2000-2010.

North Sea, Skagerrak and Kattegat. Furthermore, in 2003, the cod recovery plan for the North Sea cod stock was implemented to ensure recovery of the cod stocks by enforcing restrictions on the fishing effort (Reeves et al. 2008). The reduction of the fleet capacity was also motivated by various EU and national decommission schemes (FOI 2009). In 2005/2007, the kilowatt days gradually tended to stabilize for the majority of the fleet segments. After 2007, the kilowatt days gradually began to increase again for a few fleet segments (e.g. OTB 18-24 m and GIL 12-15 m; Appendix 3), whereas the number of vessels continued to decline. The structural changes from 2007 to 2010 may primarily be explained by changes in management system towards an owner based quota system, which also resulted in a re-allocation of quotas between vessels within the demersal fleet in Skagerrak. A centralisation of the cod quota in Skagerrak towards vessels having the highest quota share was observed.

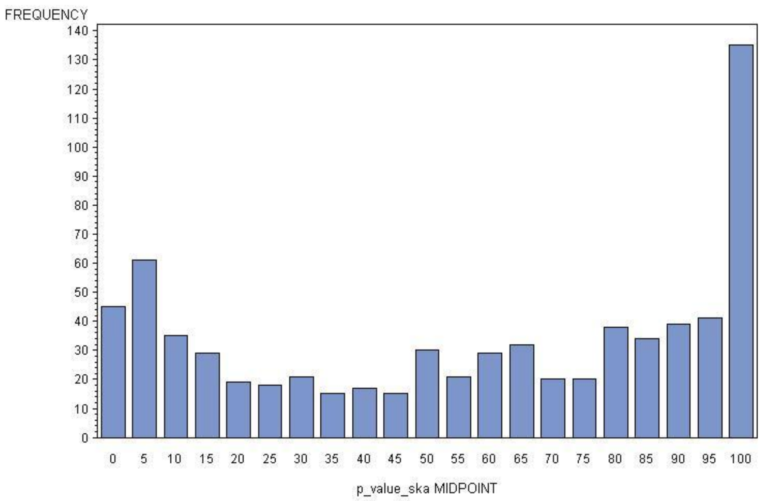


Figure 5. Distribution of vessels against proportion the yearly revenue a vessel has obtained in Skagerrak.

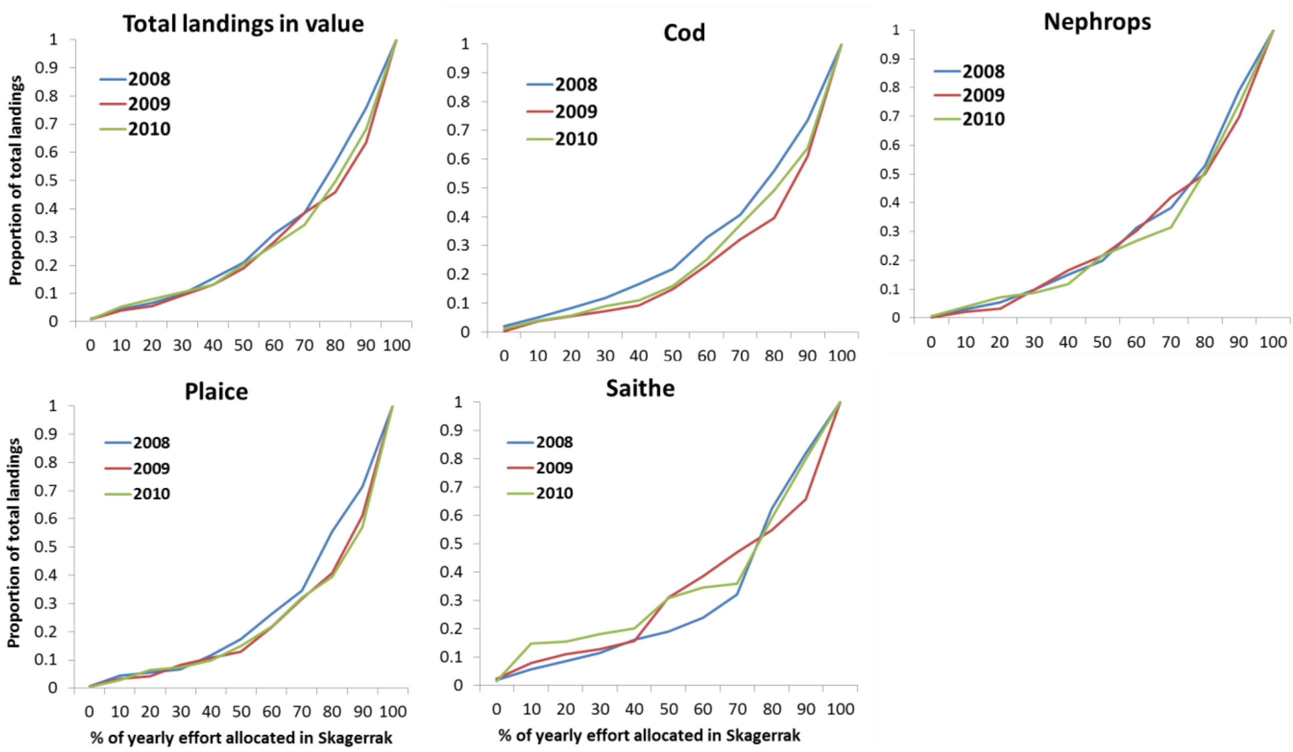


Figure 6. Cumulative proportion of vessels fishing in Skagerrak (in terms of proportion of yearly revenue) against the cumulative proportion of total landings.

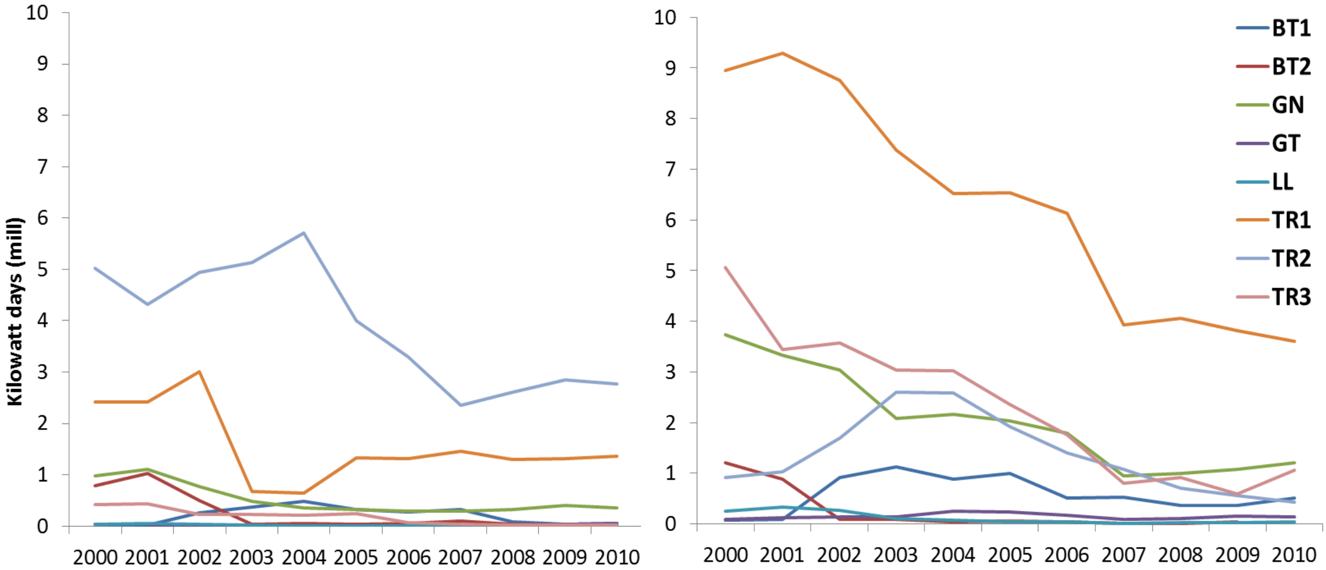


Figure 7: Development in kilowatt days by gear groups (defined accounting to EU No. 1342/2008) in Skagerrak (left) and The North Sea (right). TR1 = Bottom Trawl and seine with mesh size> = 100 mm.TR2 = Bottom Trawl and seine with mesh size 70-99 mm.; TR3 = Bottom Trawl and seine with mesh size 16-31 mm.;BT1 = Bottom trawls mesh size> = 120 mm.´;BT2 = Bottom trawls mesh size 80-119 mm.;GN1 = nets and tangle nets.

Description of the temporal and spatial fishing activity of the demersal fisheries in Skagerrak

The demersal fisheries in the North Sea and Skagerrak are characterised by a mixed fishery, where several stocks are targeted simultaneously at the same fishing ground around the year (Ulrich and Andersen 2004). A central issue of managing the demersal stocks has been how to restrict fishing on one or several species without restricting fishing on other species taken in the same fishery (a classic mixed fishery problem) (Reeves et al. 2008). The focus in the present study is on identifying and describing the dynamics of cod-related fisheries in the demersal fishery in Skagerrak. To identify cod-related fisheries, information from official logbooks and sale slips have been used including all fishing trips with mesh sizes ≥ 70 mm in Skagerrak from 2000 to 2010. A fishery (or metier) is defined as a combination of gear and landing profile at the level of a trip. This definition is slightly modified compared to the metier definition used in the EU data collection framework (DCF). The DCF metier definition at 'level 5' divides the landing profile into either a group of crustaceans or ditto of demersal fishes. This rather coarse definition of landing profile prevents the examination in more details of the dynamics in species selectivity (or targeting behaviour) of the demersal fleets in Skagerrak. If needed, all analyses in this study can be summarised into the DCF metiers categories.

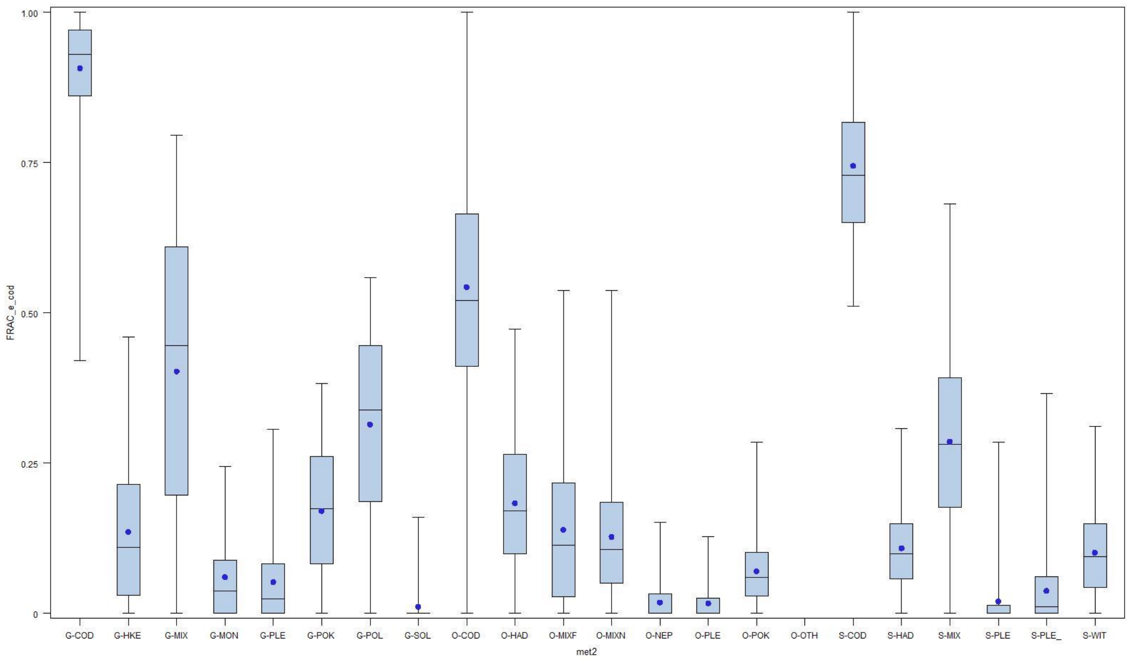


Figure 8. A box plot of the proportion (y-axis) of the cod (in weight) in the landings of each the identified fisheries (x-axis). The number of observation presented in each fishery is given in Table 3.

The first step is to split the landings from the logbook (by fishing trip) into homogenous landing profiles. Secondly, to combine the identified landing profiles with gear to label each trip in the logbook data with a *fishery* category. A common procedure for identification of homogenous landing profiles on large data is the use of multivariate statistics. Particularly, hierarchical cluster analysis (HCA) methods have frequently been applied (ICES 2003). A hierarchical cluster analysis (HCA) was applied on logbook information from the Danish demersal fishery from 2000 to 2010. The number of clusters used in the HCA was based on the level of variance within the data explained by the clusters. With app. 85 % of the variance explained only small increase in the R^2-value was found beyond 10 clusters. The identified landing profiles (or clusters) from the HCA for the main gears are presented in Appendix 4. Some of the clusters fall out to have almost similar landing profile in terms of the most dominating species. These clusters were subsequently grouped into a single landing profile. The final number of identified fisheries in the demersal fishery in Skagerrak from 2000 to 2010 is presented in Table 1. The characteristics of the majority of the identified fisheries are that only one type of gear and mesh size are used. Finally, the labelling of the identified fisheries is based on main gear and most dominant species in the landing profile, and in cases where several species are found to dominate the landing profile the fishery is labelled as mixed ('mix').

Table 1. The identified fisheries in the demersal fisheries in Skagerrak. Data is based on official logbook information from 2000 to 2010. Characteristics are summarized for 2008-2010. Gear code: GIL=Gillnet; OTB=demersal trawls; SDN=Danish seine;Speceis code: see Figure2

Fishery name	No of trips	Specific gear	Dom sp	Mean mesh size	Mean vessel length	Main species
GIL_COD	2182	GNS (>95%)	cod	159	12.5	Cod
GIL_HKE	855	GNS (>95%)		144	12.8	Hake, cod, plaice
GIL_MIX	798	GNS (86%); GTR (14%)		138	12.5	Plaice, cod, hake
GIL_MON	161	GNS (>95%)		196	12.2	Monk fish, cod
GIL_PLE	1313	GNS (>95%)		142	12.4	Plaice
GIL_POK	405	GNS (>95%)		141	13.6	Saithe, cod, pollack
GIL_POL	912	GNS (86%); GTR (14%)		140	12.8	Pollack, cod
GIL_SOL	67	GNS (>95%)		103	12.5	Sole, plaice
OTB_COD	772	OTB (>95%)		96	15.6	Cod
OTB_HAD	307	OTB (>95%)		97	18.9	Haddock, cod
OTB_MIXF	1319	OTB (>95%)		100	15.9	Plaice, cod, lemon sole, dab
OTB_MIXN	5114	OTB (>95%)		91	17.1	Nephrops, cod, witch flounder, saithe
OTB_NEP1	3197	OTB (>95%)		90	16.3	Nephrops
OTB_NEP2	2733	OTB (>95%)		90	16.3	Nephrops, cod
OTB_PLE	4370	OTB (>95%)		106	14.7	Plaice
OTB_POK	3239	OTB (>95%)		94	20.1	Saithe, cod,
SDN_COD	300	SDN (>95%)		113	16.8	Cod, plaice
SDN_DAB	358	SDN (>95%)		110	15.9	Plaice, cod
SDN_HAD	105	SDN (71%); SSC (29%)		113	21.1	Haddock
SDN_MIX	514	SDN (>95%)		109	14.4	Plaice, dab
SDN_MIX1	1130	SDN (>95%)		109	16.7	Plaice, cod, haddock
SDN_PLE	3166	SDN (>95%)		110	14.3	Plaice
SDN_WIT	229	SDN (>95%)		106	16.5	Witch flounder, cod, haddock, plaice

Cod is found in the landings of the majority of the identified fisheries, with the exception of the specialised fisheries for plaice, monkfish and *Nephrops* (Fig. 8). The distribution of cod landings between fisheries has undertaken significant changes from 2000 to 2010 (Fig. 9). In 2000, app. 60 % of the cod was landed in cod-directed fisheries, whereas these fisheries only covered app. 30 % of total landings in 2010. This is mainly explained by the dramatic decline in the cod-directed gillnet fishery (Figure 10), which however still (the latest

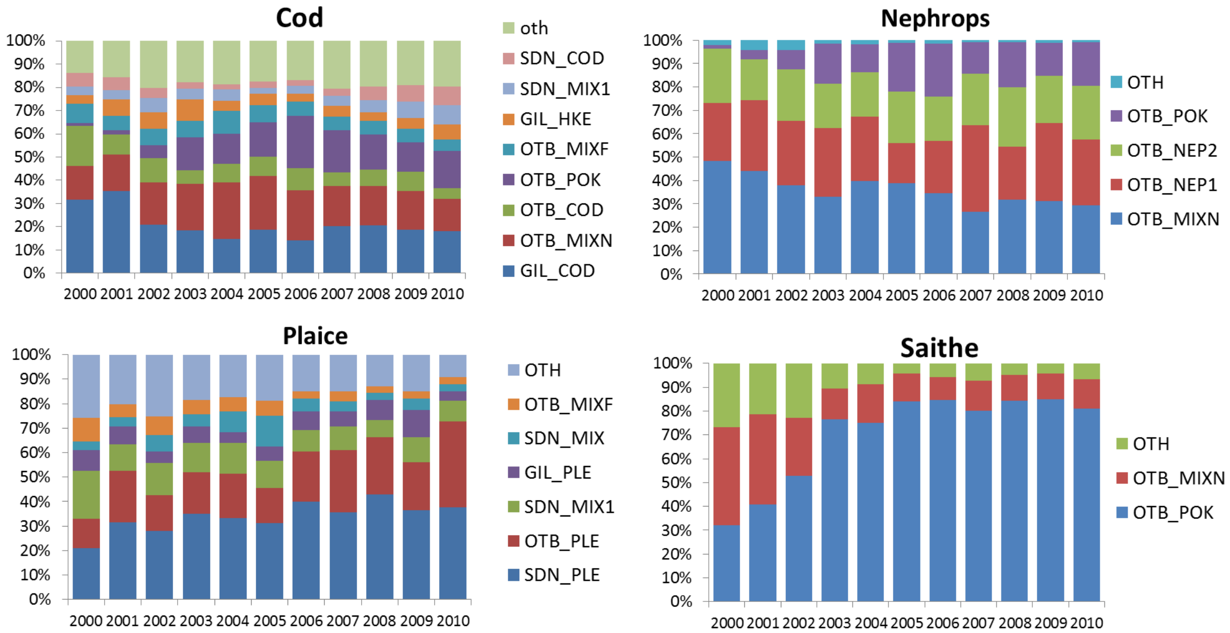


Figure 9.Total landings of main species (in weight) grouped by identified demersal fisheries in Skagerrak from 2000 to 2010.

3-4 years) is one the main cod-related fisheries in Skagerrak. But, the majority of landed cod is found in other species-directed and mixed fisheries (OTB_MIXN, OTB_POK, SDN_MIX1 and SDN_COD). Particularly in the latest years, an increased proportion of the cod has been landed in the saithe-directed fishery (app. 15-16 % of the total landings in 2008-2010).

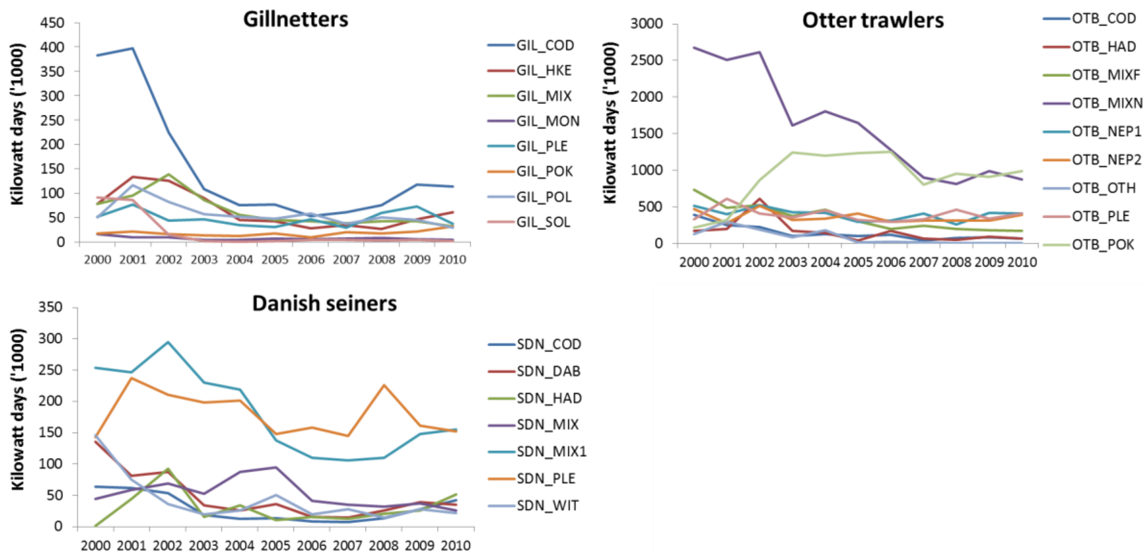


Figure 10. Distribution of kilowatt days by fisheries from 2000 to 2010.

The overall characteristic of the cod landing is that it is landed by a large majority of the identified fisheries, and that the majority of the landings are found in fisheries not directed for cod (app. 65-70 % in 2008-2010). In contrast, 60-80% of the landings of plaice, *Nephrops* and saithe are found in the fisheries directed at the respective species. A clear shift in the saithe landings from a mixed trawl fishery towards a directed trawl fishery was observed from 2000 to 2003/2005 (Fig. 9). For plaice, cod and *Nephrops*, only minor displacements were observed in the distribution of the landings between the identified fisheries.

A dramatic temporal decline in the effort allocation of particularly the cod related fisheries appears (Fig. 10). However, not clear correlation was found between the proportion of effort and the proportion of cod landed in the most dominating fisheries. Again the decline in fishing effort from 2001 to 2006 may be explained by the significant restriction in the cod quota. After 2006, increases in kilowatt days was observed for the cod-directed gillnet and Danish seine fisheries. These observations may indicate that changes in the regulation (from a monthly catch ration system to yearly quota system) have again made it profitable for individual fishers to practise a more directed fishery for cod, but still the majority of the cod is caught in fisheries not directed for cod.

The geographical distribution by season of the main demersal species

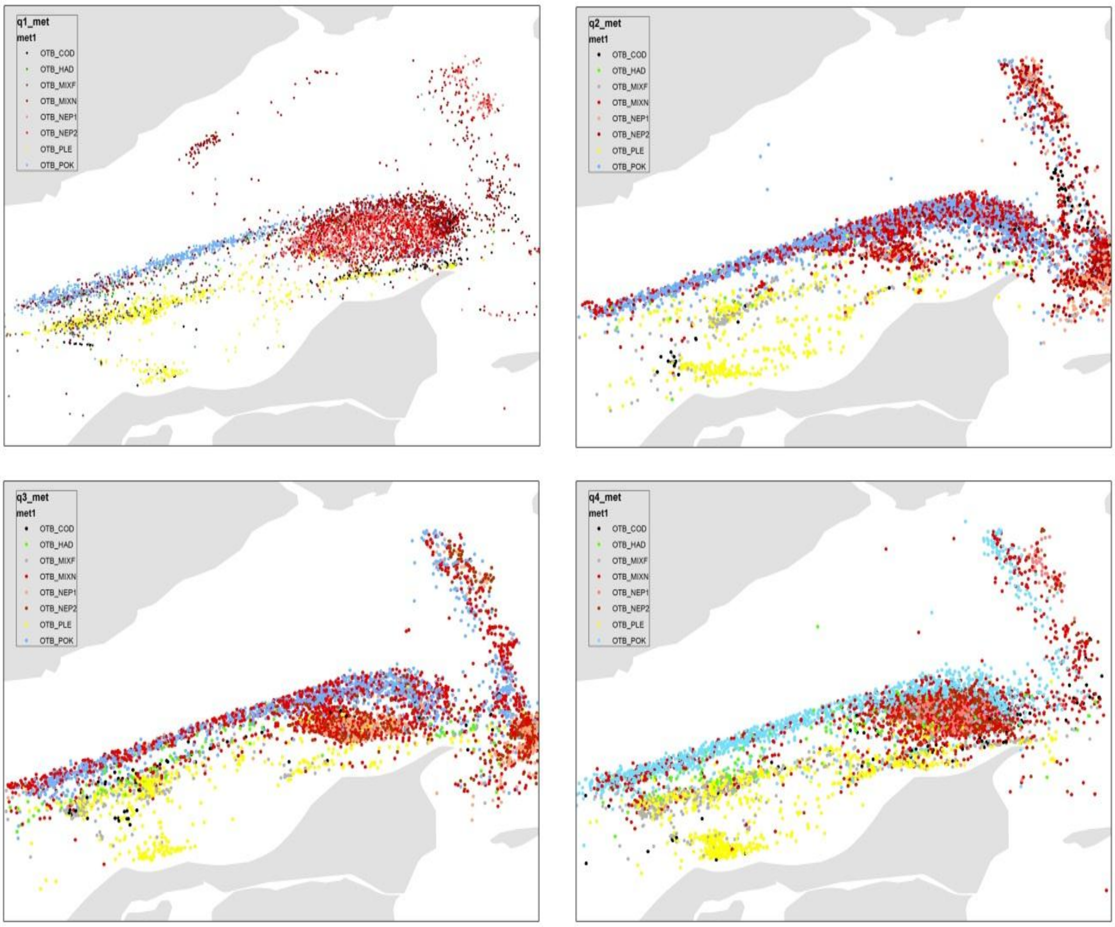


Figure 11. Geographical distribution of the defined fisheries by quarter of the year. ● cod, ● haddock, ● mixed, ● mixn, ● nep1, ● nep2, ● plaice, ● saithe

To examine the geographical distribution by season of the defined fisheries, information from logbook was merged with vessel monitoring system (VMS) data from individual vessels in the period 2005 to 2010. These data only include vessels above 15 meters, which results in very low coverage rate (in terms of the contribution to total landings in Skagerrak) for the gillnetters, whereas >80% of the total landings of the trawlers and the Danish seiners were accounted for in the combined logbook/VMS data (Table 2). For each fishing day, the mean coordinates of all registered pings (with a vessel speed between 2 and 4 knots) are estimated, and coupled with the daily landings from the logbook, and each ping represent one fishing day. The geographical distributions of the effort of the identified demersal trawl fisheries are mapped in GIS (Fig. 11). The effort is mainly distributed along the Norwegian trench at depths ranging from 50 to 300 meters as well as on the so called "Banken" west of Skagen. Visual inspection of the GIS maps indicates that the plaice fisheries are mainly allocated to the more shallow waters west of Skagen and so separated from the other fisheries. No clear separation could be found for the latter, although there was a tendency for the saithe directed fishery to be distributed on the deeper part of the Norwegian trench in the first and last quarters of the year, and a directed/mixed Nephrops fishery on "Banken" in the same quarters and along the west coast of Sweden in the two other quarters. A more detailed description of the geographical distribution of the fisheries on the four main demersal species is given in the next section.

Table 2. Percentage of total landings accounted for by the combined logbook-VMS data from the demersal vessels divided by gear type in Skagerrak from 2008 to 2010.

	Cod	Haddock	Hake	Lemon sole	Nephrops	Plaice	Saithe	W flounder
Gillnetter(GIL)	8%	17%	24%	10%	-	5%	5%	-
Otter trawler (OTB)	78%	90%	88%	79%	83%	64%	96%	93%
Other (OTH)	92%	-	90%	91%	-	79%	-	-
Danish seiners (SDN)	80%	98%	92%	86%	-	54%	99%	93%

The same approach was used to describe the geographical and seasonal distribution of the landings and targeting dynamics of the demersal trawl and Danish seine fisheries on the four main species (cod, plaice, *Nephrops* and saithe). The total landings of each species and the proportion of the individual species to the total landing (in value) were estimated in each predefined grid of 1x1 nautical mile for each quarter of the year from 2008 to 2010.

The geographical distribution of the cod landings clearly illustrates that majority of the cod landing are relatively small (trawlers: Appendix 5 and Danish seiners: Appendix 6) and only a small number of trips is exclusively targeting cod. These findings combined with findings of fisheries analysis clearly show that cod is primarily caught as a high value by-catch species in the demersal fishery in Skagerrak. However, a growing cod-directed fishery mainly by gillnet and Danish seine vessels currently exists.

A distinct seasonal pattern in the geographical allocation of the *Nephrops* landings was found (Appendix 7) with a clearly directed fishery for *Nephrops* on the main *Nephrops* fishing grounds. *Nephrops* is mainly distributed on the "Banken" in the first quarter of the year, and in the eastern part of Skagerrak close to the boarder to Kattegat and along the west coast of Sweden in quarter 2. In quarter 3 (the main fishing period), the landings of *Nephrops* is more broadly distributed. In quarter 4, it is again centred mainly on the "Banken".

The plaice landings are mainly found west of Skagen in the more shallow waters with main landings in quarters 2 and 3 (Appendices 8 and 9). The landings are characterised by having only minor overlap in the spatial distribution with the other demersal species. The majority of plaice is caught in a plaice-directed fishery. There is a high geographical overlap in the distributions of the landings of the trawler (Appendix 8) and the Danish seiners for saithe and plaice (Appendix 9). But currently no high spatial resolution information exists on the gillnetters as the majority of the gillnetters are below 15 meters.

The saithe landings are mainly distributed along the Norwegian trench (Appendix 10). In the first quarter, the main saithe landings are primarily distributed in the western part of Skagerrak, whereas the landings are more broadly distributed in the second and the third quarters to cover also the central part of Skagerrak. High proportions of saithe in the landing were found on the same fishing grounds as those where the highest landings were observed.

Observer information on discard

Since 1995, DTU Aqua and the Danish Fishermen's Organization have cooperated to collect data on discards in the demersal fishery. Participation in the discard sampling programme is voluntary and permission by the skipper is required. The observer from DTU Aqua has no relation to the control unit, and the fishing practice is assumed to be unaffected by the observer's presence. For each observed haul, an estimate of the total catch weight is made by the fishermen and the observer in collaboration. The total catch is divided into the retained (landed) and discarded components by the commercial fishermen. The total weights of each individual species retained are recorded. If the abundance of a species is small, total numbers and lengths are recorded, otherwise a subsample is taken, and the numbers and lengths recorded are raised to total catch. The total discarded portion of the catch is approximated from the total catch weight, a subsample taken, and then sorted by the observer into species. Total weights and numbers of each discarded species in the subsample are determined and raised to total discard based on the total approximated discarded weight. All fish species are measured to the nearest cm. The proportion of young gadoids (cod, whiting, haddock and saithe) obtained at haul level is presented in Figs 6(b) and 6(c) of the Synthesis.

Current management system

The TAC system

One of the main objectives in fisheries management is to maintain fish stocks at a sustainable high level. The main tool for controlling the overall fishing mortality is done by setting of a total allowed catch (TAC) for a given stock. The EU commission, through the Council of Ministers is responsible for setting the yearly TAC for the commercial important stocks in European waters. The TAC level is often based on scientific advice, but the final TAC agreements are decided on a yearly EU minister meeting, which not always follows the biological advice. The allocation of the quotas among individual member states is based on historical rights (also known as the principle of relative stability). Additionally, agreement among individual member states of exchanging national quotas can take place. However, most of these agreements are not permanent and can quickly change from one year to another. Allocation of the national quota to fleets or vessels varies considerably among member states. In Denmark until 2007, the quotas of all demersal stocks were allocated through a quota rations system, where a regulatory committee (represented by representatives from the fishermen organisation, the fishing industry and the ministry) could assign a catch ration (weekly, bimonthly or monthly) on a given stock. This system was in principle open for all fishing vessels owning a fishing licence, where the ration size depended on the size of the fishing vessel and the overall catch level set by the regulatory committee. In 2007, an owner-based management system was enforced in the Danish demersal fishery giving the quota rights to individual vessels (also known as the FKA system). The main objectives of changing to an owner based management system were to improve the profitability in the demersal fishery and to obtain a more sustainable exploitation of the stocks, with particular focus on reducing the discards (FVM 2007). In the beginning, a number of restrictions on the transferability of quota shares between vessels were enforced. However, these rules were gradually relaxed, and the system today acts almost as an individual transferable quota system (ITQ).

Currently, very little is known about to which extent the FKA system has influenced the exploitation pattern on the demersal stocks. During the period from 2007 to 2009 the nominal fleet capacity was reduced from 959 active vessels in 2007 to 664 active vessels in 2009 (Andersen et al. 2010). In the latest two years (2009 and 2010), the yearly economic statistics for fisheries have reported a general increase in the profitability in the Danish demersal fisheries. These changes are most certainly a result of the implementation of the owner based management system (or FKA system). Besides the documentation of a reduction in the nominal effort and number of fishing vessels there exists currently no scientific evidence that the FKA-system has resulted in reduction of discard of undersized fish and quota species in general. However, a number of indications points in the direction that the new system have created an economic incentive for the individual fisher to reduce his possibilities to come in a situation, where his quota is exceeded and forced to discard quota species.

The FKA system resulted in a shift from a weekly/monthly catch ration where the fisher continuously attempted to maximise his catches (in most cases in volume) with limited possibilities for planning his fisheries, to a situation where individual vessel owns a yearly quota. This has given the individual fisher the possibility of optimising his profit by maximising the revenue of the landing and minimizing the cost. Additionally, the quota was made transferable, so it has also given the individual fisher the opportunity to continuously adjust his fishing activities by leasing, buying or selling quotas. The transferability in the system gives the fisher a tool to balance the quota composition with his actual catches. In a highly mixed demersal fishery like in the Skagerrak and the North Sea, the fisher does not know exactly what he is going to catch. So the system is also highly dependent on how flexible the individual fisher is to compensate for the uncertainty in his catches to avoid situation where his is forced to discard quota species. In ITQ fisheries around the world, several types of tools have been implemented to improve the flexibility for quota balancing (Sanchirico et al. 2006). However, unique for the Danish FKA system compared other ITQ-fisheries, is the implementation of a ‘fish pool’ system (established by the fishing industry itself). The ‘fish pool’ system has given the Danish demersal fishers the possibility on a day-to-day basis to lease/swap quota(s) with other members within the ‘fish pool’. The ‘fish poll’ system has been very popular and today app. 80 % of the FKA quotas is landed within the eight ‘fish pools’ that currently exists in the Danish fishery.

The combination of the flexibility of buying and selling on permanent or yearly basis and leasing/swapping on daily basis have created a highly potential flexible system for the Danish demersal fishers to balance their quota compared to the actually catches, thereby minimising the discard of particularly over-quota species. However, occurrence of situation, where economic incentive for the fishers to high-grade or fish in locations with high abundance of undersized fish, cannot be excluded.

Quota evolution and uptake for demersal stocks in Skagerrak

The total landings, level of TAC, and TAC utilisation for cod, plaice, *Nephrops* and saithe in Skagerrak is presented in Table 3. The national cod quota was significantly reduced in the period from 2002 to 2007, whereas it was increased again from 2007 to 2010. However, the level in 2010 was only 70 % of the quota level in 2002. An almost similar pattern was observed for the haddock quota. The *Nephrops* and saithe quotas gradually increased during the period, whereas the plaice quota was relatively stable during the time period (except for 2003). The majority of the quotas has not been fully utilized in the latest years due to several reasons such as too high trading prizes, speculations etc. But the low utilization level for haddock and hake indicates that the TAC level for these two stocks has not been a restrictive factor for the demersal fleet in Skagerrak.

Table 3. Quota size and utilisation for the main demersal stocks in Skagerrak 2000-2010

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Quota (in tonnes)									
Cod (Skagerrak: IIIa)	5536	3092	3116	3128	2651	2261	2594	3374	3860
Plaice (Skagerrak; IIIa)	7888	10419	7327	5963	6150	6241	8400	8496	7299
Nephrops (IIIa,b,c,d)	3282	3274	3283	3454	4144	4063	4039	4196	4197
Saithe (IIIa,b,c,d + IV)	5711	7882	8349	7923	7598	7391	9142	9699	8471
Hake (IIIa,b,c,d)	739	828	1077	1171	1327	1575	1655	1590	1685
Haddock (IIIa,b,c,d)	3867	1784	3107	3054	2453	2690	2056	1823	1560
TAC utilization (in %)									
Cod (Skagerrak: IIIa))	100%	99%	98%	96%	95%	99%	99%	89%	85%
Plaice (Skagerrak: IIIa)	82%	47%	78%	76%	103%	87%	82%	66%	94%
Nephrops (IIIa,b,c,d)	101%	84%	90%	86%	60%	72%	80%	86%	89%
Saithe (IIIa,b,c,d + IV)	99%	88%	96%	94%	98%	74%	88%	91%	95%
Hake (IIIa,b,c,d)	58%	40%	38%	25%	18%	20%	31%	40%	20%
Haddock (IIIa,b,c,d)	98%	98%	36%	20%	42%	40%	52%	69%	73%

Technical measures

To protect the juvenile and valuable species a cohesive set of technical measures (EU no 850/98) was implemented in 2000 including specific mesh sizes, minimum landing size, gear restrictions, limits on by-catch as percentage of total catch, effort restrictions and area closures. The objective was to encourage the fishers to be more selective in the way they are fishing. Before 2004, the *Nephrops* fishery in Skagerrak was characterised by the use of 70 mm mesh sizes, with a minimum restriction of 30 % of *Nephrops* in the landings (in weight). However, in April 2004, a sorting grid and square meshes in the cod-end was enforced for towed gears using 70 mm mesh size. The result was that all Danish fishers changed to 90 mm mesh size, where no by-catch or target species limitation was enforced.

In 2003, the ‘days at sea regulation’ was implemented in connection to the cod recovery plan. From 2003 to 2008, the effort restriction was defined by the monthly number of fishing days on a yearly basis for each gear category. In 2009, the effort system was modified to be managed by the individual member states (a result of the cod recovery plan in accordance with Council Regulation (EC) No 1342/2008 of 18 December 2008). A national kilowatt schemes for Kattegat, Skagerrak and the North Sea was implemented and a national kilowatt quota was set for each gear category. Since 2009, all Danish registered vessels have to apply for a kilowatt license that give them access to a certain amount of kilowatt days for each gear category. In general, the number of kilowatt days given to each vessel is based historical fishing activity in the different gear categories in 2008. For individual vessels exist some level of transferability for selling/burying kilowatts days in the kilowatt days system. But it is highly unclear how this system work and to which extent the demersal vessels in Skagerrak currently are restricted in kilowatt days. However, the allocated kilowatt days in Skagerrak have not yet (2010) been fully utilized (Appendix 11). But a reduction of e.g. 15 % (due to e.g. the cod recovery plan) will most probably imply a direct restriction in effort level.

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The demersal fisheries

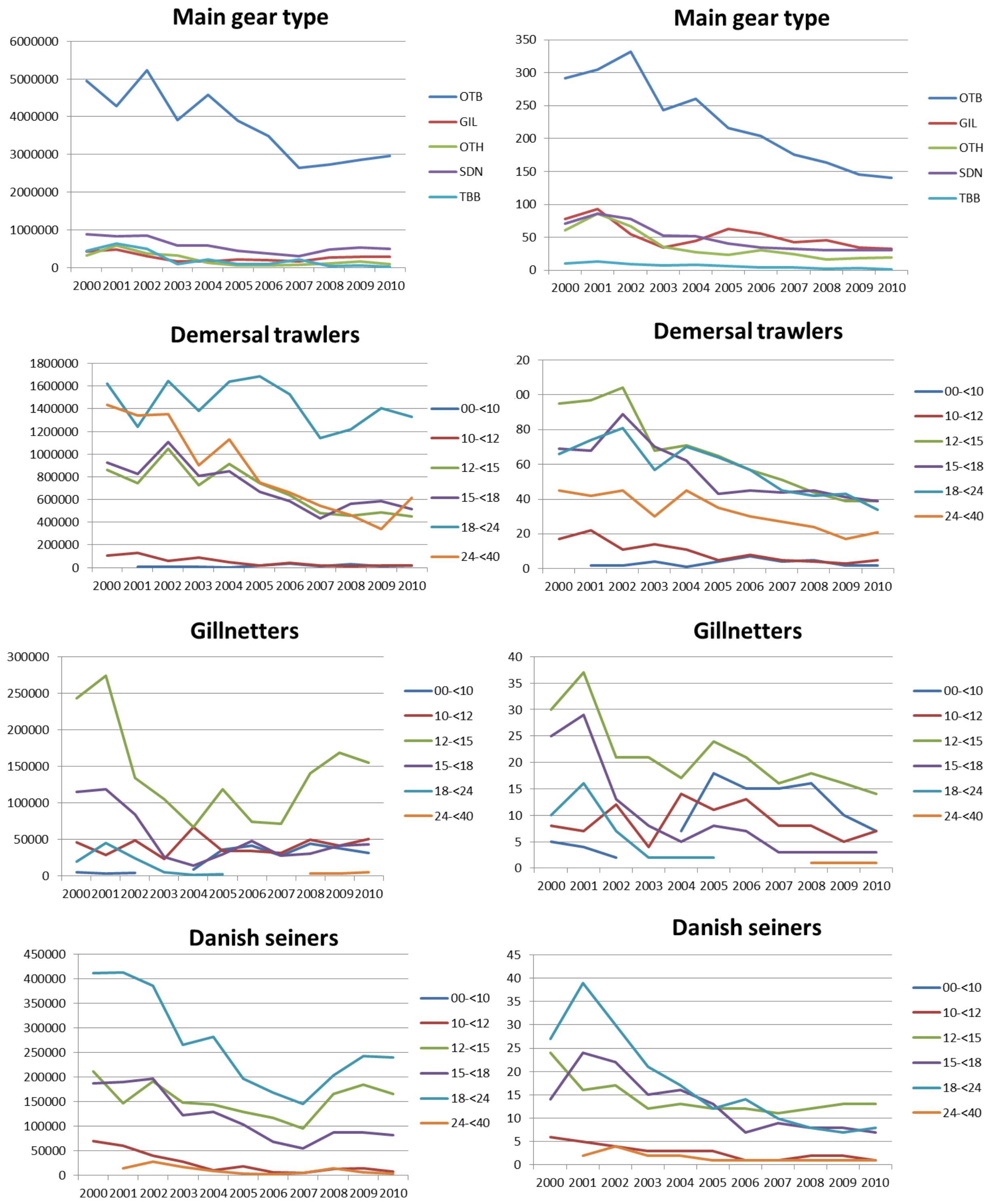
Appendix

Appendix 1. Landings in value (mill DKK.) of demersal species in Skagerrak from 2000 to 2010.

	NEP	PLE	COD	WIT	POK	HAD	LEM	MON	SOL	HKE	TUR	DAB	POL	CAT	CRE	LIN	Oth
2000	118.1	74.5	114.2	29.1	3.6	7.8	17.6	13.6	18.5	3.8	7.1	3.5	3.1	2.7	1.2	0.9	10.3
2001	97.7	110.5	97.5	23.1	5.2	12.2	11.9	13.6	18.8	6.0	9.1	4.2	2.9	2.2	1.5	1.1	12.7
2002	144.6	81.7	87.8	24.3	10.8	24.0	13.2	13.0	9.7	8.8	8.8	6.5	3.2	2.3	1.8	1.3	11.7
2003	71.5	68.5	45.8	18.9	11.7	9.3	9.5	6.4	4.6	5.6	4.6	4.1	2.2	1.2	0.9	0.8	7.2
2004	77.3	72.1	47.3	20.7	11.5	9.1	9.4	9.5	6.6	7.2	4.7	3.1	2.0	1.4	0.8	1.0	8.3
2005	102.8	62.4	46.0	19.4	16.1	4.6	11.7	8.6	8.4	6.0	4.4	4.6	2.2	1.1	0.6	0.9	5.4
2006	111.2	83.2	48.6	18.6	21.9	10.0	9.1	8.8	9.0	4.3	3.6	3.0	1.7	0.6	0.8	1.0	7.0
2007	118.2	75.9	54.2	16.2	16.7	10.6	13.6	9.7	6.5	4.7	7.1	3.0	2.9	1.2	0.9	0.9	6.6
2008	97.3	87.1	56.4	12.4	22.1	9.4	7.8	8.7	7.4	7.2	5.6	2.4	2.8	0.9	0.8	0.6	5.5
2009	91.7	50.5	54.7	11.9	24.1	10.3	6.1	9.9	5.8	7.1	4.0	2.6	3.2	0.7	0.6	0.7	4.2
2010	110.1	58.1	60.1	12.0	31.1	11.3	6.8	8.8	4.3	4.4	2.9	2.0	5.4	0.9	0.6	0.6	4.4

Appendix 2. Landing in Weight (tonnes) of demersal species in Skagerrak from 2000 to 2010.

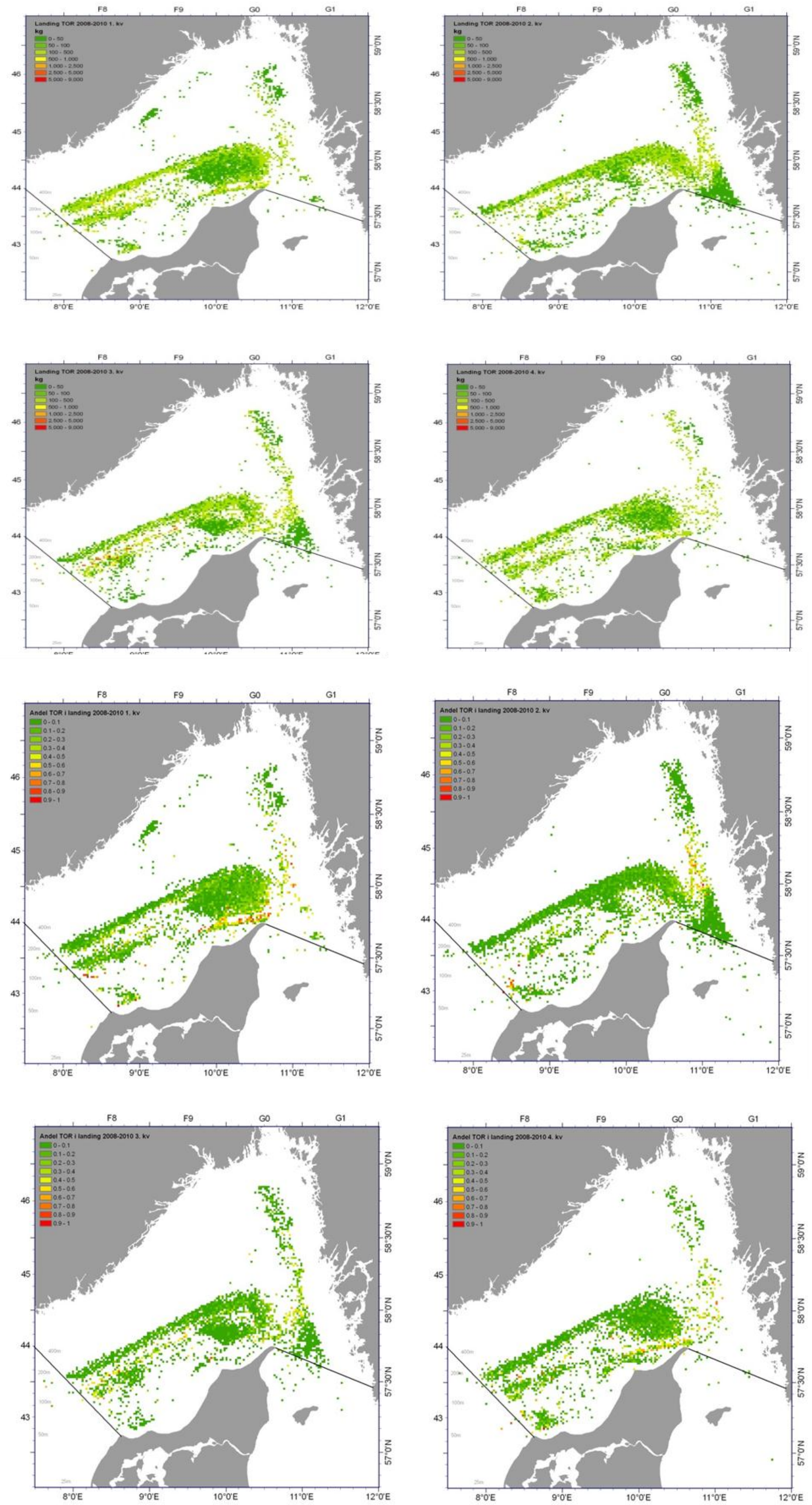
	NEP	PLE	COD	WIT	POK	HAD	LEM	MON	SOL	HKE	TUR	DAB	POL	CAT	CRE	LIN
2000	1714	5817	5307	1613	557	758	524	337	279	184	112	321	152	113	74	67
2001	1281	8178	4075	1111	704	1046	341	322	240	248	156	452	135	74	72	81
2002	1897	5860	3819	1160	1781	2623	344	324	132	318	135	718	163	81	78	104
2003	1300	4253	1965	835	2298	1051	314	176	59	227	70	475	111	36	50	72
2004	1490	5133	1905	927	2296	851	334	262	84	305	62	437	95	45	50	92
2005	1601	3979	1898	795	2623	439	354	236	106	226	62	517	120	33	37	73
2006	1412	5679	1674	567	2920	787	237	215	95	179	45	399	76	18	38	67
2007	1588	4949	1611	528	2116	795	312	235	59	245	87	393	132	36	42	61
2008	1645	6208	1862	411	2858	783	193	220	82	406	80	335	116	27	34	44
2009	2003	5069	2266	520	2856	1002	188	261	73	509	61	363	150	23	36	58
2010	1864	6175	2454	486	2827	952	237	209	47	296	34	315	240	26	28	46



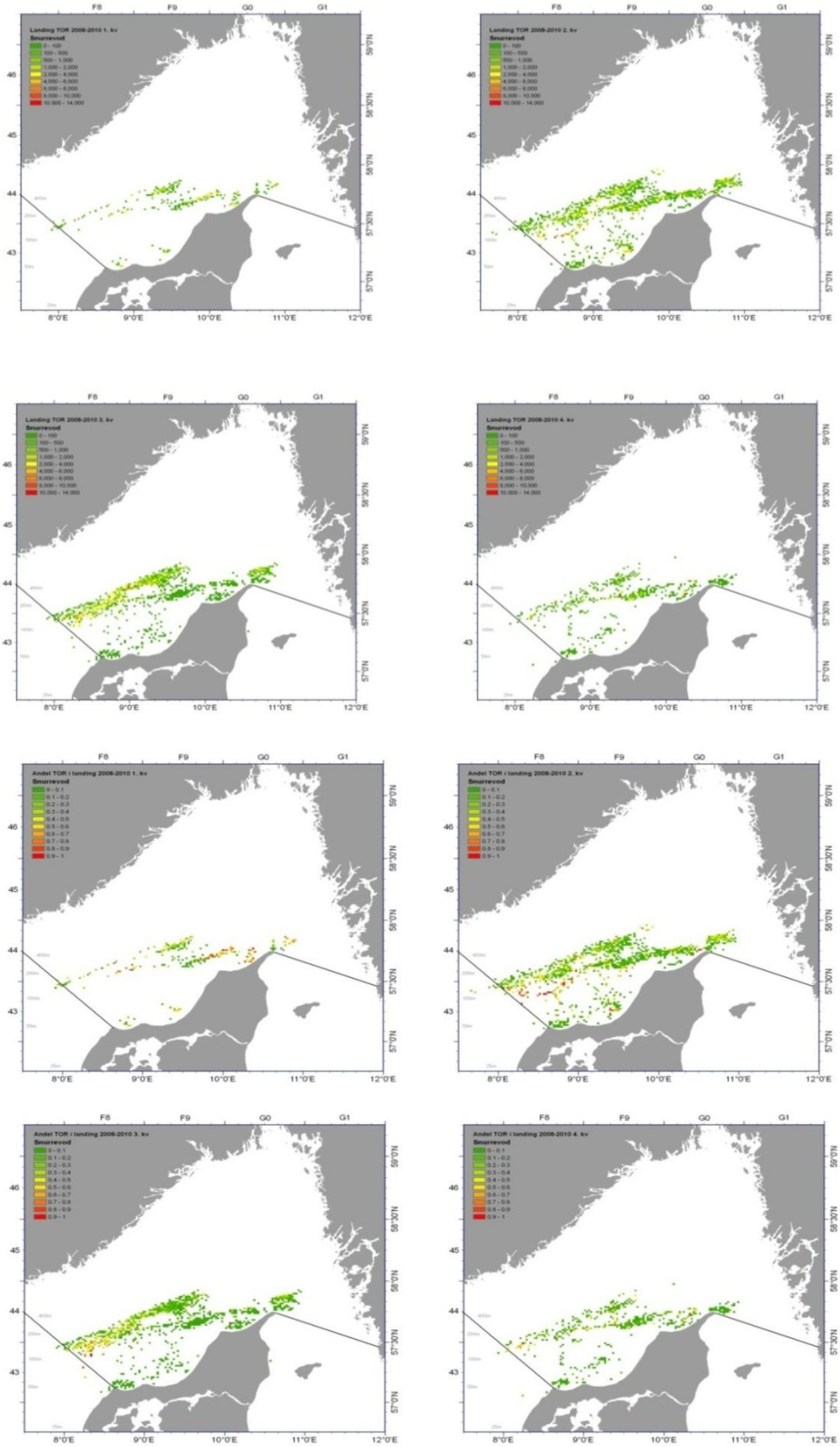
Appendix 3. Changes in fleet capacity for the demersal fishery in Skagerrak from 2000 to 2010. Left figures: Kilowatt days. Right figures: number of vessels. Top figures: all demersal vessels grouped by vessel type (main gear type). Remaining figures: grouped by vessel length classes for demersal trawlers, gillnetters and Danish seiners, respectively.

Appendix 4. Landing profile from Cluster analysis (mean fraction) from 2000 to 2010.

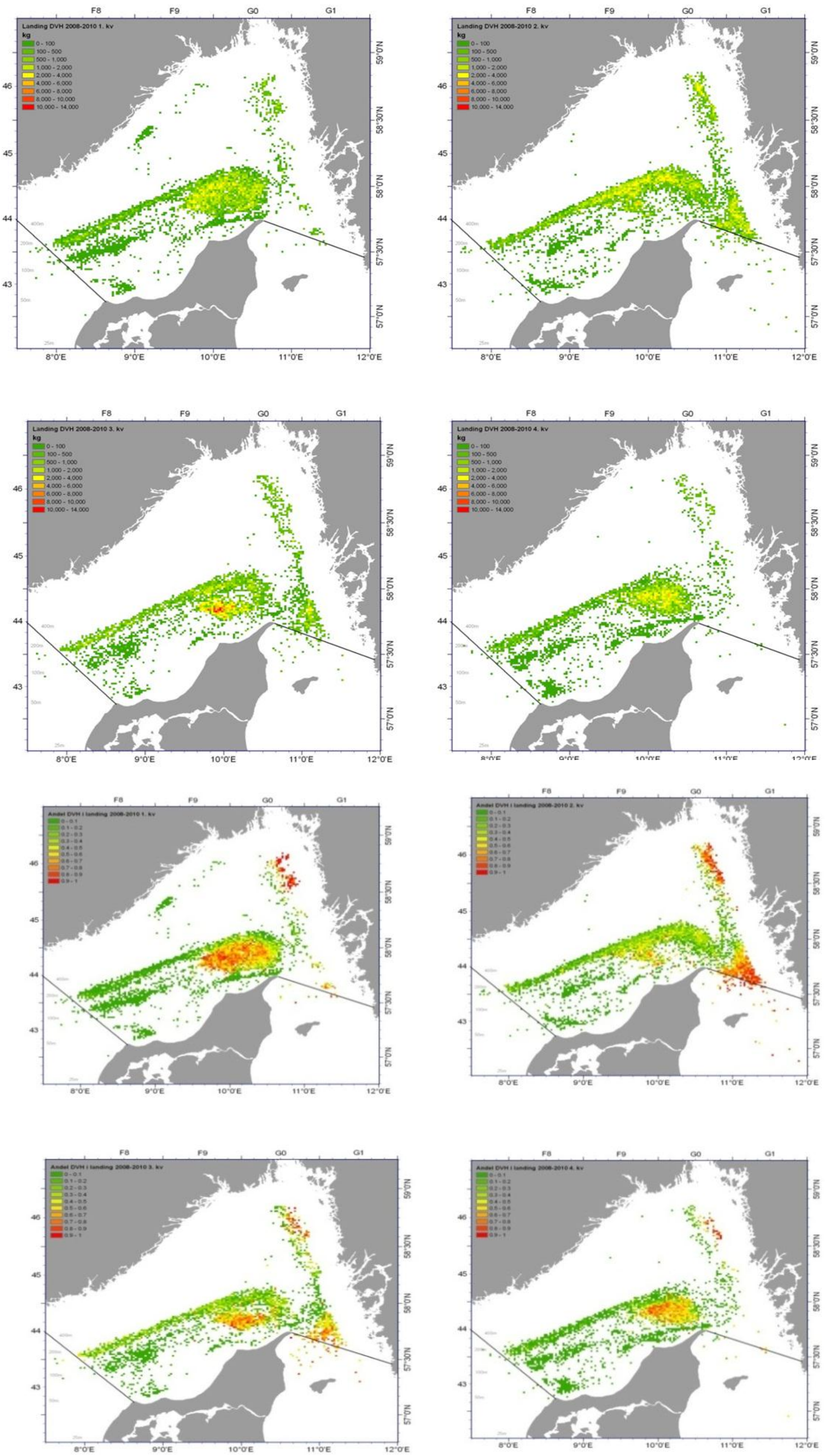
	TRIP	NEP	PLE	COD	POK	WIT	HAD	HKE	LEM	SOL	TUR	MON	POL	DAB	CAT	CTC	LUM	CRE	LIN	OTH
GIL_COD	11718	0	2	91	0	0	0	0	1	0	0	0	2	0	0	0	0	1	0	0
GIL_HKE	4558	0	16	59	3	0	1	3	3	1	0	1	7	1	1	0	0	2	1	1
GIL_MIX	4059	0	29	21	4	0	3	15	7	3	1	2	3	1	2	0	2	5	1	1
GIL_MON	610	0	9	17	1	0	0	2	1	0	4	55	3	0	1	0	0	7	0	1
GIL_PLE	4100	0	92	2	0	0	0	0	1	2	1	0	0	1	0	0	0	1	0	1
GIL_POK	1086	0	0	33	56	0	1	0	0	0	0	0	11	0	0	0	0	0	2	0
GIL_POL	4509	0	4	11	0	0	0	0	6	2	1	1	71	2	1	0	0	3	0	1
GIL_SOL	616	0	10	6	0	0	0	0	0	76	1	0	0	2	0	0	0	3	0	1
OTB_COD	4594	2	7	73	3	3	3	1	2	1	0	1	1	1	0	0	0	0	1	1
OTB_HAD	2424	5	5	14	6	3	58	2	2	0	0	1	1	1	0	0	0	0	1	1
OTB_MIXF	7636	1	31	30	2	1	5	1	11	1	1	1	1	8	1	1	2	0	0	1
OTB_MIXN	27100	28	8	21	10	11	6	4	1	2	0	3	1	1	0	0	0	0	1	2
OTB_NEP1	12843	91	2	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1
OTB_NEP2	10370	67	6	9	4	3	2	3	1	1	0	1	1	0	0	0	0	0	0	1
OTB_OTH	539	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	95
OTB_PLE	13222	0	72	8	0	0	1	1	5	1	1	0	0	7	0	0	0	0	0	1
OTB_POK	12062	10	2	11	58	5	6	2	1	0	0	2	0	0	0	0	0	0	1	1
SDN_COD	1196	0	14	76	1	1	2	1	1	0	0	0	1	2	0	0	0	0	0	0
SDN_DAB	1509	0	41	35	1	3	3	1	3	0	0	0	0	8	0	0	0	0	0	4
SDN_HAD	379	0	9	8	2	4	70	2	1	0	0	0	0	1	0	0	0	0	0	1
SDN_MIX	2484	0	67	4	0	0	1	1	2	0	0	0	0	21	0	0	0	0	0	4
SDN_MIX1	4197	0	58	14	3	5	11	2	2	0	0	1	0	3	0	0	0	0	0	1
SDN_PLE	10396	0	90	1	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	1
SDN_WIT	741	0	12	18	2	45	14	3	2	0	0	1	0	0	1	0	0	0	0	1



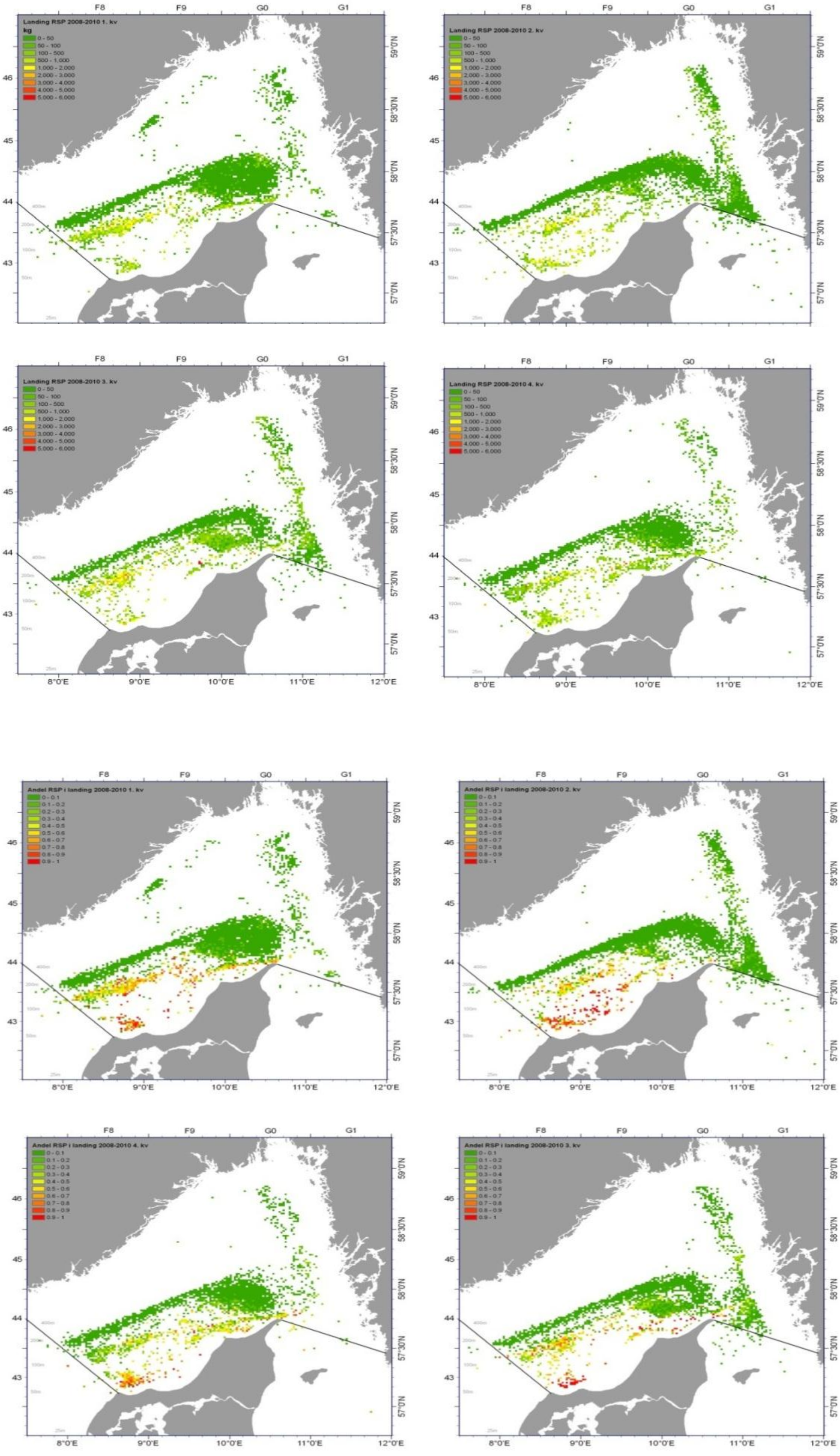
Appendix 5.Geographical distribution of trawl landings of cod in Skagerrak by quarters (2008-2010). -4: Total landing in weight. 5-8: The proportion of cod in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.



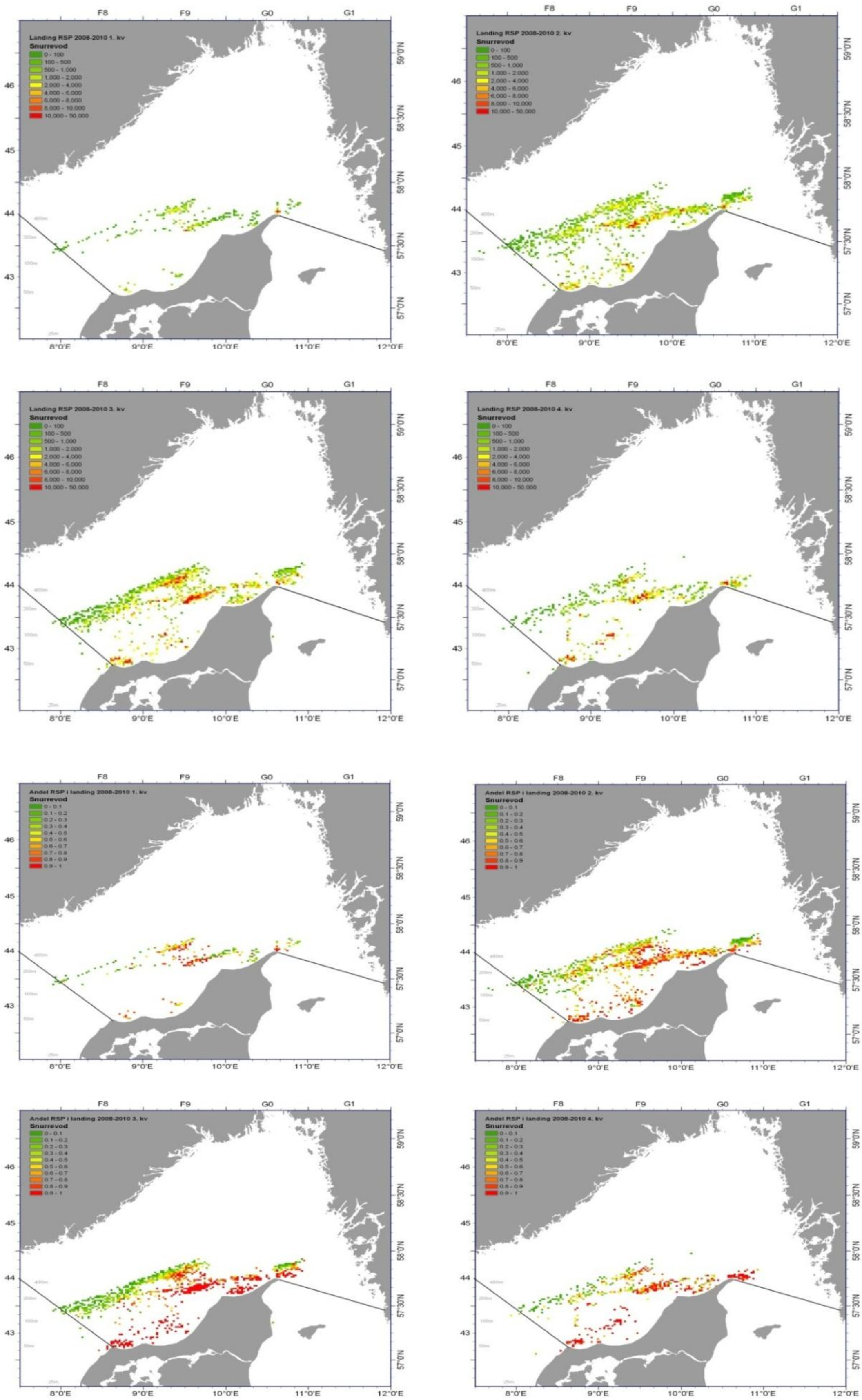
Appendix 6. Geographical distribution of Danish seine landings of cod in Skagerrak by quarters (2008-2010). 1-4: Total landing in weight. 5-8: The proportion of cod in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.



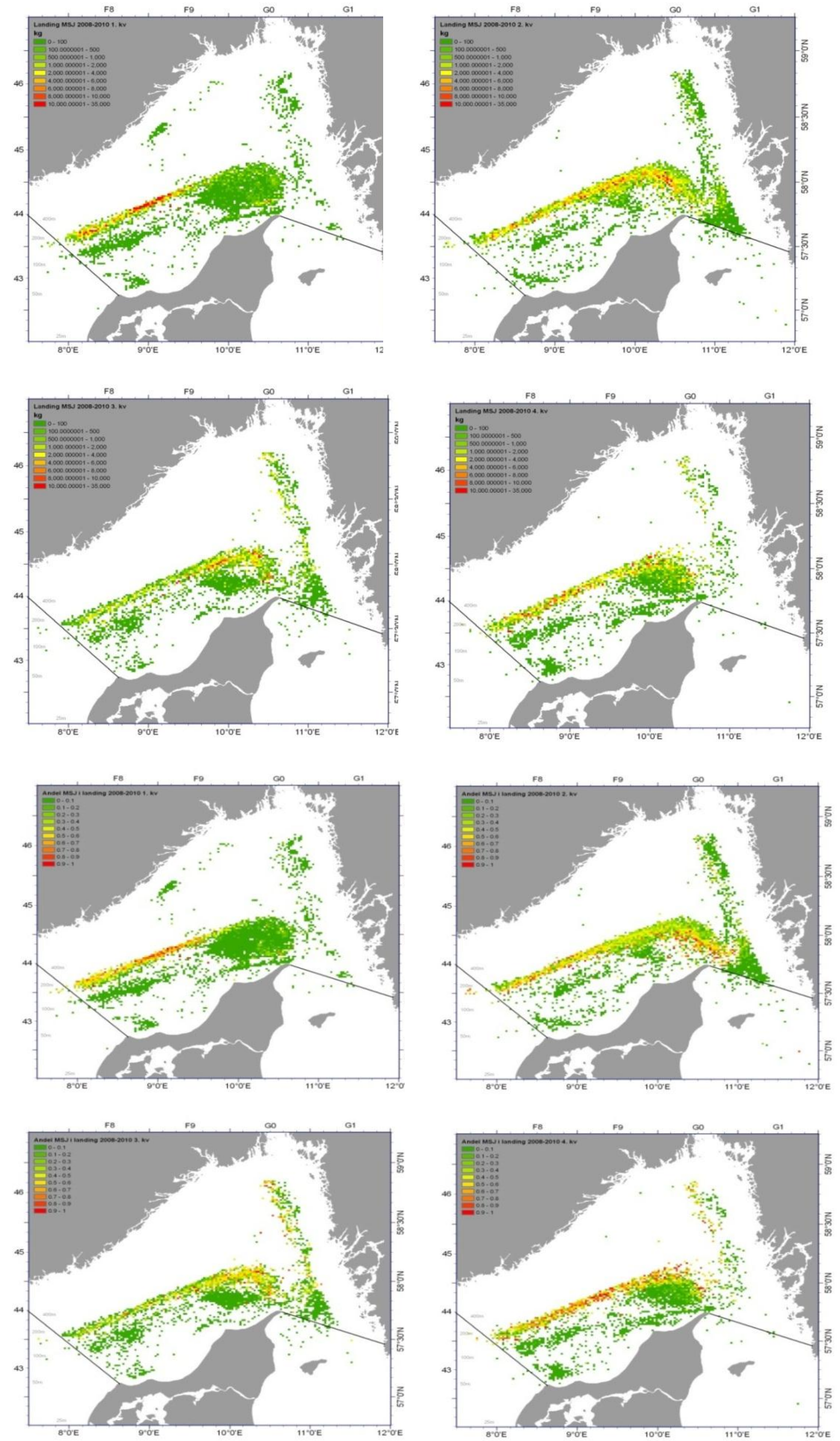
Appendix 7. Geographical distribution of *Nephrops* landings in Skagerrak by quarters (2008-2010). 1-4: Total landing in weight. 5-8: The proportion of *Nephrops* in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.



Appendix 8. Geographical distribution of trawler landings of plaice in Skagerrak by quarters (2008-2010). 1-4: Total landing in weight. 5-8: The proportion of plaice in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.



Appendix 9. Geographical distribution of Danish seine landings of plaice in Skagerrak by quarters (2008-2010). 1-4: Total landing in weight. 5-8: The proportion of plaice in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.



Appendix 10. Geographical distribution of trawl landings of saithe in Skagerrak by quarters (2008-2010). 1-4: Total landing in weight. 5-8: The proportion of saithe in the landings (in value). Each dot represents the average coordinates of the daily landings for all demersal fishing vessels above 15 meter. See more detailed description of the data applied in the main text.

Appendix 11. Quota of kilowatt days and its utilization in the North Sea, Skagerrak and Kattegat. The data is extracted from the web page of Ministry of Food, Agriculture and Fisheries

2009

	Kattegat				Skagerrak/Nordsøen			
	Kvote	kW-dage	Pct. udnyttelse	Havdage	Kvote	kW-dage	Pct. udnyttelse	Havdage
*TR1	212768	90108	42,4	519	6.911144	4818649	69,7	13049
*TR2	2070883	1725480	83,3	8.461	6.061661	3258785	53,8	11116
*TR3	42776	87282	20,4	289	3.920732	563188	14,4	736
*BT1	0	.	.	.	1316589	352815	26,8	278
*BT2	0	.	.	.	106658	52073	48,8	35
*GN1	96048	79215	82,5	595	1.962340	1371228	69,9	8167
*GT1	23684	21.63	91,3	162	198783	170159	85,6	1121
*LL1	140	.	.	.	44283	6428	14,5	51

2010

	Kattegat				Skagerrak/Nordsøen			
	Kvote	kW-dage	Pct. udnyttelse	Havdage	Kvote	kW-dage	Pct. udnyttelse	Havdage
*TR1	197929	57116	28.9	368	4892761	4674836	95.5	12866
*TR2	1967506	1923347	97.8	9212	4106634	2985266	72.7	98
*TR3	523126	39019	7.5	220	4391356	1021349	23.3	1179
*BT1	0		.		1157265	514002	44.4	424
*BT2	0		.		88645	3678	4.1	3
*GN1	115456	63499	55	499	2307977	1436591	62.2	8013
*GT1	22645	14661	64.7	139	224124	176	78.5	1247

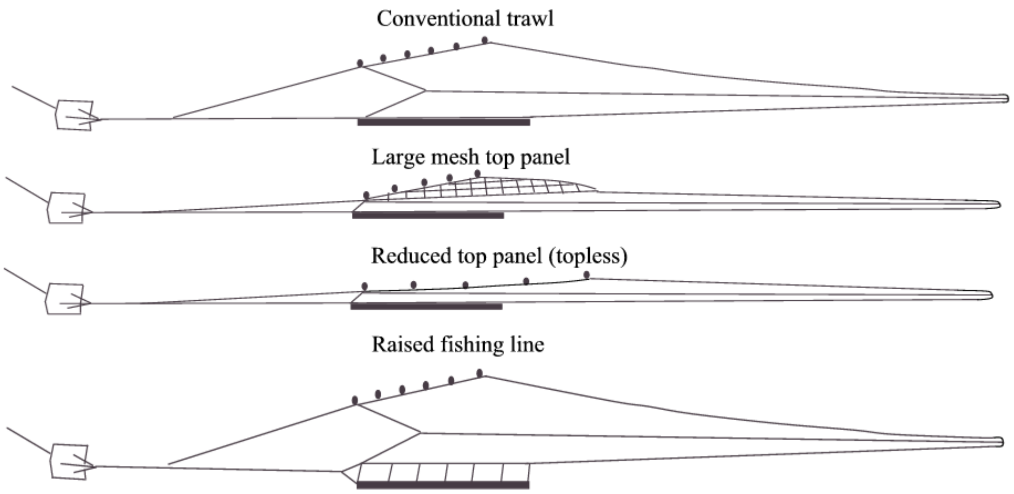
Gear definition:

TR1 = Bottom Trawl and seine with mesh size> = 100 mm.
TR2 = Bottom Trawl and seine with mesh size 70-99 mm.
TR3 = Bottom Trawl and seine with mesh size 16-31 mm.
BT1 = Bottom trawls mesh size> = 120 mm.
BT2 = Bottom trawls mesh size 80-119 mm.
GN1 = nets and tangle nets.
GT1 = Trammel nets
LL1 = Longlines

Work package C

Selective trawls

by Niels Madsen



Selectivity and development of trawls catching cod in the Skagerrak today and in the future

The fishery in the Skagerrak is depending on more species than the fishery in the Kattegat. Due to severe reductions in the cod fishery Norway lobster is today the most important species in both areas. Management and legislation concerning selectivity in trawls reflects this matter since relatively small mesh sizes are used to retain Norway lobster. To improve the selectivity, the mesh size of the codends used in the Skagerrak and Kattegat has been increased by legislation in several steps during the past decades. The minimum allowed mesh size was 60 mm in 1989 (Kirkegaard et al., 1989) and was increased up to 90 mm recent years (Frandsen et al., 2009). There has also been an increase in the codend twine thickness and a shift from single twine to double twine in this period. An important reason for this development is to increase the strength of the codend to balance the increased efficiency of the fishery (*e.g.* higher catch rates). Since both factors are expected to decrease selectivity (Lowry and Robertson, 1995; Tokaç et al., 2004; Herrmann and O'Neill, 2006; Sala et al., 2007) the maximum allowed twine thickness is 5 mm when using double twine. Most Danish fishermen use 4 or 5 mm double twine today. Also the codend circumference can influence the mesh opening and increasing circumference will decrease the selectivity (Reeves et al., 1992). Therefore a maximum of 100 open meshes is allowed in codends. Use of devices like round straps, to assist handling of the catch, might also affect the selectivity (Herrmann et al., 2006) but there is no overview on use of such devices (Madsen and Valentinsson, 2010).

The codend selectivity for cod in traditional diamond mesh codends (4 mm and 5 mm double twine) have been estimated in the Kattegat and Skagerrak fishery in several recent experiments (Madsen and Stæhr, 2005; Madsen et al., 2008; Frandsen et al., 2009; Frandsen et al., 2010). The selection factor (L50/mesh size, where L50 is the 50% retention length) for cod are estimated to be in the range of 1.60 to 2.45 in these experiments having a L50 on only 14-22 cm for a 90 mm codend used today. This suggests that an improved selectivity is needed to increase the size at first capture and decrease potential discard of cod. One option is to increase the mesh size from 90 mm to 120 mm as used in the North Sea. A catch comparison experiment estimated a 59% reduction of cod below 40 cm but no reduction in catches of cod above (Krag et al., 2008). There was, however, a reduction around one-third in the catch of Norway lobster above the minimum landing size as well as an reduction in most other commercial important species. Consequently an increase in mesh size to 120 mm would cause a considerable economical loss of Norway lobster and this is furthermore not an efficiently method to reduce catches of larger cod if necessary (*eg*. Kattegat). It is therefore of high importance to develop selective devices that can be used to target Norway lobster but also other commercial important species.

Obviously the mesh form is important when considering improving the selectivity. Herrmann et al. (2009) measured the morphological parameters of Skagerrak cod that determine the ability of the cod to penetrate different mesh types. Based on simulations they investigated diamond, square, rectangular and hexagonal meshes and found that the highest L50 value for cod for a given mesh size occurs in hexagonal meshes but also a relatively high L50 for square meshes. Conveniently square meshes can be made from conventional netting. Full square mesh codends have been tested in the Skagerrak-Kattegat fishery indicating an increased selection factor for cod but also for Norway lobster (Frandsen et al., 2010) leading to a reduced loss of individuals above MLS. A simple way to increase the mesh opening is to turn the mesh 90° (T-direction, henceforth T90) because the knots will determine the initial mesh bar angle. A T90 codend was introduced in the legislation for the Baltic Sea (Madsen, 2007; Herrmann et al., 2007). Tested in the Kattegat-Skagerrak a higher L50 of cod is indicated but also for Norway lobster causing a considerable loss of individuals above MLS (Madsen et al., 2008).

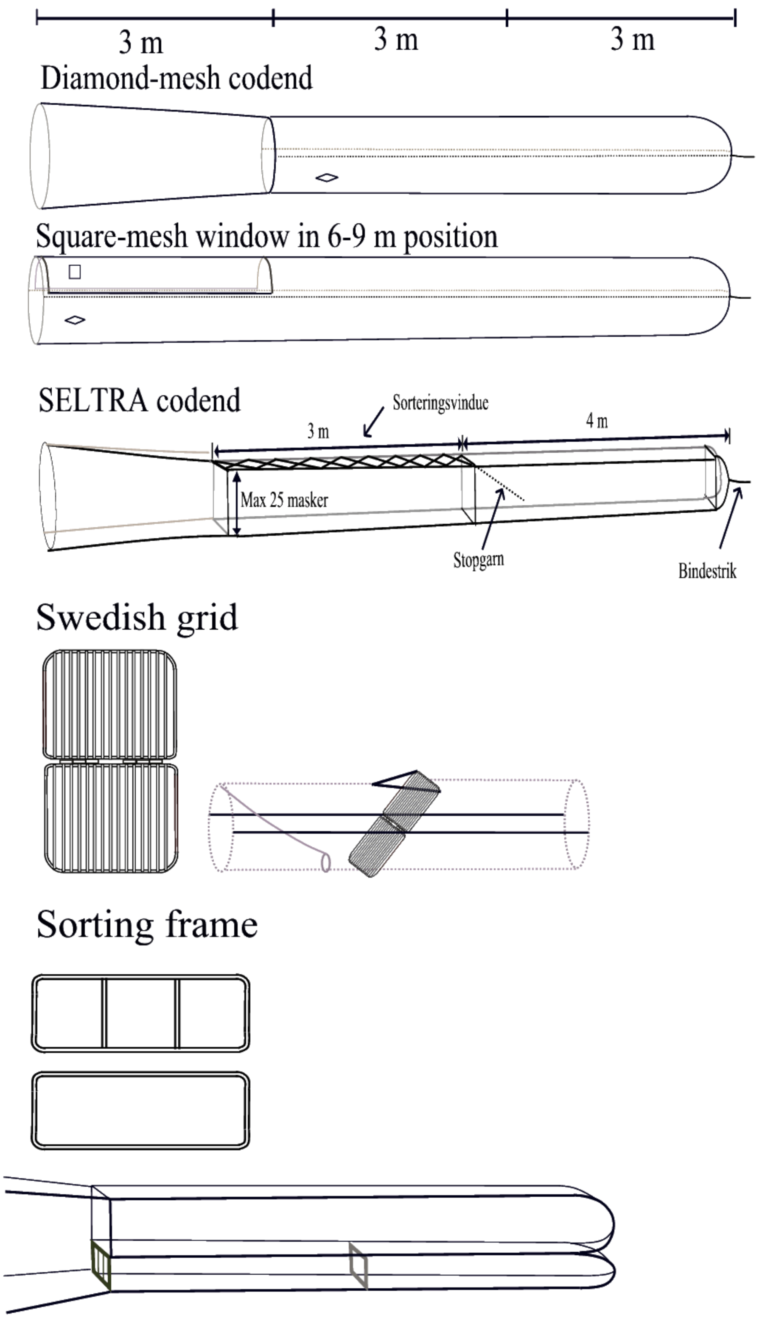


Figure 1. A conventional diamond mesh codend, the codend with the window in 6-9 m position as described in the legislation for Skagerrak, the SELTRA codend that is used in Kattegat, a Swedish grid which is used in Kattegat and Skagerrak by Swedish fishermen and a sorting frame that could be a future option for the mixed fisheries in Skagerrak.

The escape window (henceforth window) is a panel with meshes of a different shape or size than in the remaining part of the trawl. The chief benefit is that it is a simple and cheap method of improving the selectivity. The principle is that a window placed in a top panel offers an escape possibility for fish while Norway lobster and flatfish are expected to pass underneath. A 120 mm window placed in 6-9 m position from the end of the codend is implemented in legislation in the Skagerrak today (Fig. 1). However, Krag et al. (2008) and Frandsen et al. (2009) were not able to document a clear effect on cod when using a window in this position. There were indications of an effect (close to be statistically significant) but the statistically power of the experiments might be too low to detect a potential effect. Windows placed in other positions have been tested indicating an increased selectivity of cod (Madsen and Stæhr, 2005), when placed in positions where they will affect Norway lobster catches. It has also been demonstrated that a position further back in the codend (3-6 m from the end) improve the selectivity of cod but also causing some loss of Norway lobster. The SELTRA concept (also known as the sorting box) is developed to make a substantial improvement in the selectivity of cod while maintaining the catch of Norway lobster. The concept is built on a four panel section to achieve a higher stability in the codend and enhanced escape of cod through a window while maintaining the catch of Norway lobster (Fig. 1). This codend gives a high reduction of cod (> 85%) (Madsen et al., 2010; Madsen and Valentinsson, 2010). However, plaice also escapes through the window when larger mesh sizes are used (300-400 mm) in the window. As a part of the cod avoidance plan for Kattegat the SELTRA codend with a 300 mm window was implemented for use in a partially closed area (Madsen and Valentinsson, 2010). The SELTRA codend with a 180 mm window mesh size is implemented in the whole Kattegat area from 2011 in the first 3 quarters of the year.

Grid systems utilise mechanical sorting by size and is widely used in shrimp fisheries around the world. There has been an increasing interest in the use of grids in Norway lobster fisheries in recent years. In general, the reduction of cod is very high (90-100%) for individuals larger than 35 cm using a 35 mm bar spacing (Catchpole et al., 2006; Valentinsson and Ulmestrand, 2008; Frandsen et al., 2009; Drewery et al., 2010). A loss of Norway lobster is recorded in some experiments (Catchpole et al., 2006; Frandsen et al., 2009; Drewery et al., 2010) while no loss is observed in others (Valentinsson and Ulmestrand, 2008). It has recently been tried to increase the bar distance for grids used in Kattegat and Skagerrak to reduce the potential loss (Madsen et al., 2008; Madsen et al., 2011). Further development have also been made to increase handling properties and to test other grid designs that can retain more Norway lobster and flatfish (Madsen et al., 2008; Valentinsson and Ulmestrand, 2008; Madsen and Valentinsson, 2010; Madsen et al., 2011). Grids are used in Norway lobster fisheries in Kattegat and Skagerrak by a substantial number of the Swedish trawler fleet (Madsen and Valentinsson, 2010). A major problem when using grids in the Skagerrak is that the bars easily can be blocked by (fish, debris etc). Therefore other concepts seem to be more realistic options.

Two experiments by Krag et al. (2009a; 2009b) found that 18% and 13% respectively, of the cod enter the lowest part of a frame covering 25% of the total height in the extension of a trawl. Furthermore it was found that bars can be used to guide the cod upwards (Krag et al., 2009a). Following these principles, Madsen et al. (2008b) tested a 30 cm high sorting frame with two guiding bars to guide fish upwards while Norway lobster are expected to penetrate the frame. This concept is illustrated in Fig. 1. It was found that 88% of the Norway lobster above MLS and about 40% of the cod penetrated the frame. Improvement of this concept is a very likely future solution for the Skagerrak mixed fishery and offers the possibility of fishing with 2 codends having different selectivity.

Over the past several decades there has been a tendency in Kattegat in the development of trawls away from directed Norway lobster trawls towards designs that have improved efficiency for fish. Recent development work has been conducted to develop trawls with increased catch rates for the Norway lobster and decreased catch rates for fish by reducing the door distance and using longer wings, lower trawls heights and large mesh top panels although it has not been technically possible to assess the effects (Madsen et al., 2008). Since otterboards and sweeps have no significant influence on the capture process of Norway lobsters (Main and Sangster, 1985; Thorsteinsson, 1986; Newland and Chapman, 1989), reducing the swept area by 50% might reduce cod catches by the same amount.

Several whole trawl concepts have been tested in the Skagerrak. Madsen et al. (2006) tested a large mesh top panel (Fig. 2) in a fishery for flatfish in the Skagerrak with a low height and 400 mm meshes in the upper panel combined with a 130 mm square mesh section. This concept had a high reduction of cod below 40 cm and was still able to catch more plaice large cod indicating increased efficiency (Madsen et al., 2006). A very recent experiment with a reduced top panel (also known as the topless trawl) (Fig. 2) yielded a reduction of particularly larger cod, whereas there were no indications of a loss of Norway lobster and flatfish (Krag and Madsen, 2010). The topless trawl with a SELTRA codend is implemented as an option in the Kattegat fishery and might be a likely option for the Skagerrak fishery. Krag et al. (2010) developed and tested a selective haddock trawl modified by raising the fishing line (Fig. 2) about 60 cm above the seabed allowing cod to escape downwards under the trawl and haddock upwards into the trawl. There was a considerable reduction of cod but with a noticeably higher reduction at night. The reduction of haddock was minimal during the day (1%) and slightly higher (11%) during the night. The separation of cod was length dependent where larger fish raised higher than smaller individuals. This a potential option in the Skagerrak when targeting saithe or haddock.

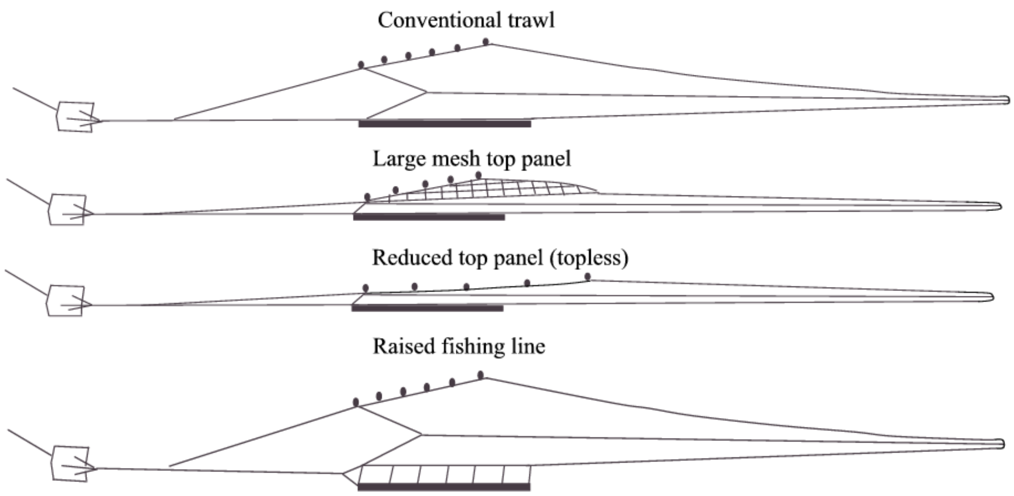


Figure 2. Different trawl concepts of relevance for the future Skagerrak fishery.

Improving selectivity of cod in the future trawl fishery in Skagerrak

The technical regulations of the Skagerrak fishery are being considered at the moment. More selective devices are likely to be introduced in the near future. The cod stock is general in a better condition than in the Kattegat but exploitation pattern could be improved by increasing size at first capture and reducing discard. The more mixed nature of the Skagerrak fishery will make it necessary to develop concepts different from those implemented in the Kattegat fishery today.

Several selective devices presented here are likely options for the Skagerrak fishery. Using these devices it is possible to maintain an economically viable fishery on Norway lobster and flatfish. In contrast an increase in mesh size from 90 mm to 120 mm, as proposed by Norway, will make substantial reductions in particularly Norway lobster catches. The effectiveness of the selective devices in relation to cod is demonstrated in Fig. 3.

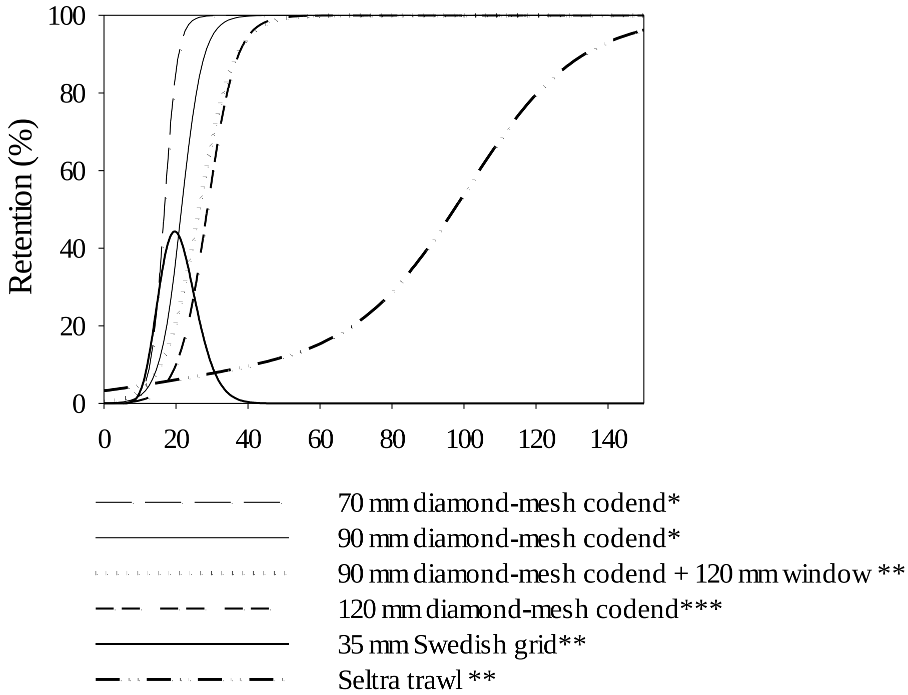


Figure 3. Cod selection curves for different gears according to minimum allowed mesh/bar size specified in previous (*) or current (**) legislation for the Kattegat and Skagerrak and in current legislation for the North Sea (***). Figure from Madsen and Valentinsson (2010).

Improving selectivity should be considered in a broader context than improving the selectivity of the used gears. In general it is a question of changing the whole fishery pattern. Fisheries in the Skagerrak are in the future expected to be more selective and hence directed towards target species. This will increase the demand for Fisherman experience and use of new electronic devices (improved sonar systems, underwater cameras etc.). In general the trawl designs are expected to be changed from the combi-designs used today, made to catch all important species, to designs targeting certain species like Norway lobster and flatfish. Furthermore incentives to reduce discard are introduced by voluntary certification and use of new technology like electronic monitoring that will make it possible to change from landings to total catch quotas that will give fishers incentive to avoid discard (Kindt-Larsen et al., *in press*). Motivation of fishermen to adopt new and more selective fishing gears may greatly help the implementation of legislation (Tschernij et al., 2004; Suuronen et al., 2007). Rewards like unrestricted effort, extra quota and access to some important fishing areas are examples of relevant incentives for accepting increased use of selective gears (Krag et al., 2008; Valentinsson and Ulmestrand, 2008; Madsen and Valentinsson, 2010).

Survival of cod escaping through codend meshes during the towing process is generally high (Soldal et al., 1993; Suuronen et al., 1996; 2005; Ingólfsson et al., 2007) but the recognition of a relatively large escape during haul-back (Grimaldo et al., 2009) causes concern about an increased mortality induced by additional stress and physical damage. It is important that this matter is considered more carefully when developing, testing and implementing selective devices in the future.

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Work package D

Oskar surveys

Geographical distribution of catch rates and catch composition

by Kai Wieland & Maria F. Pedersen

Surveys with two commercial trawler and one gillnetter

Sampling strategy and survey data analysis

Surveys were conducted with the trawlers HG-350 Luna and FN-234 Canopus and the gillnetter S-444 Dortigi in June/July 2008 as well as in February, May and October 2010 (Tab. 1). The surveys covered the entire Skagerrak at depths between about 10 and 200 m.

Table 1. OSkar survey dates (fishing days) and number of valid stations.

Survey	Vessel	Sampling period	Number of valid stations	Depth (m)
SK1	HG-350 Luna	3/7 - 8/7/2008	29	17 - 185
	FN-324 Canopus	27/6 - 2/7/2008	29	50 - 189
	S-544 Dortigi	30/6 - 6/7/2008	44	12 - 128
SK2	HG-350 Luna	17/2 - 22/2/2010	28	37 - 218
	FN-324 Canopus	17/2 - 22/2/2010	30	48 – 176
	S-544 Dortigi	19/2 - 23/2/2010	38	13 – 82
SK3	HG-350 Luna	14/5 - 19/5/2010	30	24 – 192
	FN-324 Canopus	14/5 - 19/5/2010	30	34 – 201
	S-544 Dortigi	21/5 - 25/5/2010	29	14 – 81
SK4	HG-350 Luna	22/10 - 27/10/2010	30	31 – 204
	FN-324 Canopus	22/10 - 27/10/2010	29	46 – 204
	S-544 Dortigi	23/10 - 29/10/2010	34	11 – 33

The survey area was divided into 5 $*$ 5 nautical mile (nmi) squares, and the western part was allocated to HG-350 Luna whereas the eastern was allocated to FN-234 Canopus (Fig. 1). Each of these two areas contained the same numbers of elements (68 squares) of which 30 squares were expected to be covered in the 6 fishing days available to each survey and vessel. 22 squares were selected randomly prior to each survey and 5 additional squares were selected by the skipper during the survey. This approach should ensure a wide spread of the sampling locations with a representative coverage of the entire area. In addition, 3 squares from each of the vessel specific list of stations located in the adjacent vessel specific survey areas were chosen for trawl calibration experiments in 2010. The precise trawl tracks within the 5 $*$ 5 nmi squares were chosen by the skipper. Trawling across the boundaries of the squares was allowed as long as the major part of the trawl track was within the assigned square. Examples of the realized station distribution are shown in Fig. 2.

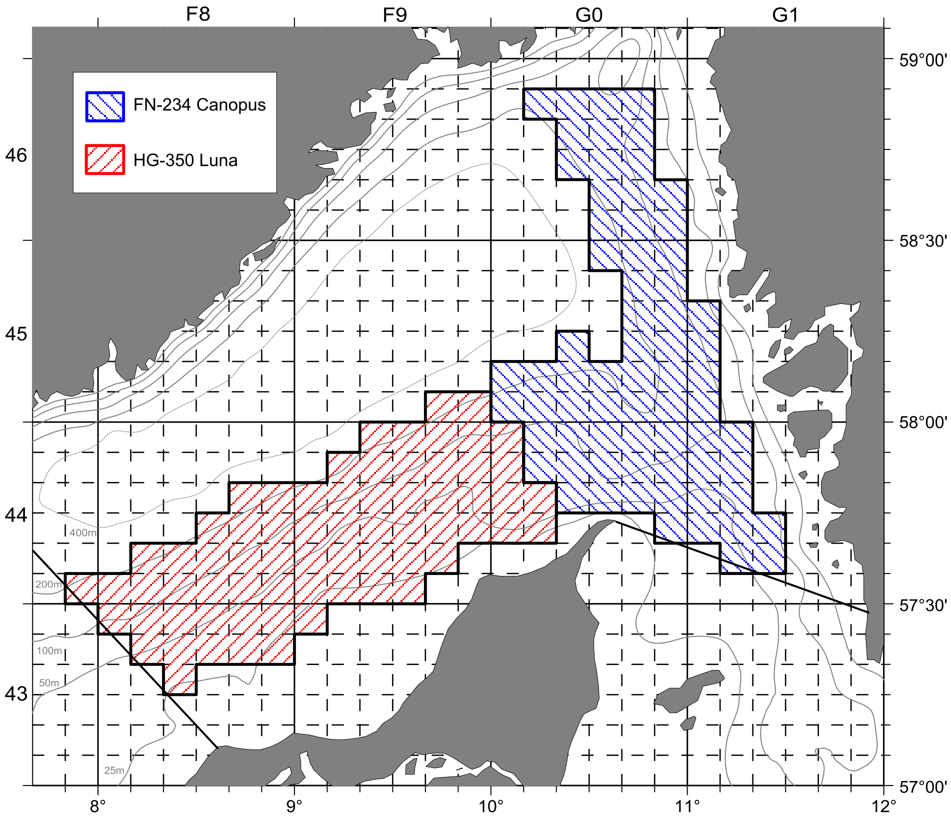


Figure 1. Survey area allocated to the two trawlers (February, May and October 2010, minor difference compared to June/July 2008).

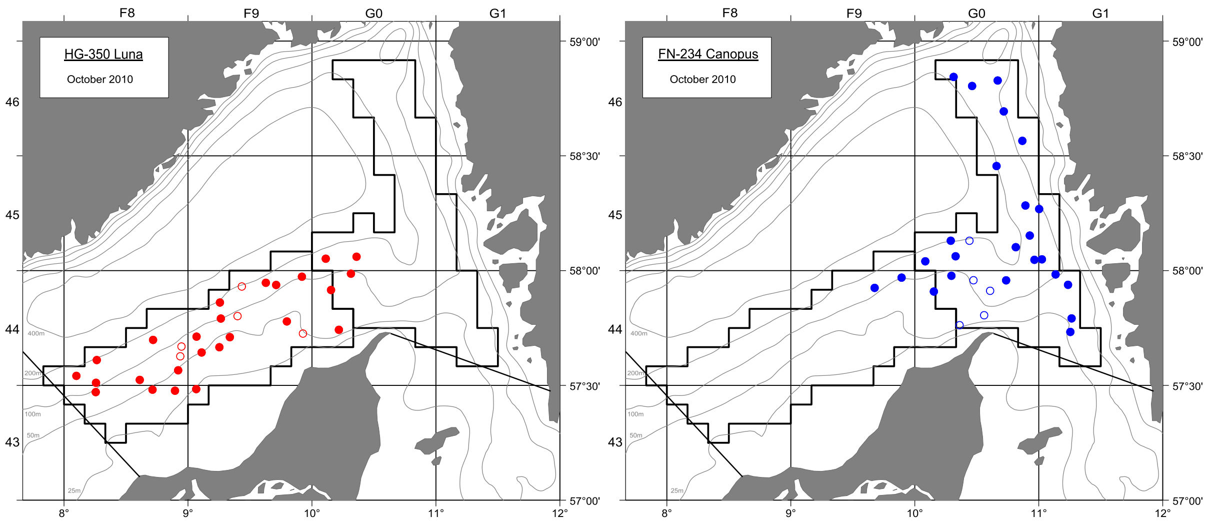


Figure 2. Locations of trawl stations in the Oskar survey in October 2010 (filled circles: random; open circles: skipper selection).

The trawlers used two trawls of the same type simultaneously with a roller clump between them (twin trawl fishing, three warp towing system). Both vessels used TV-4 trawl with 90 mm codend mesh size and no escapement window. Towing speed was 3 knots and towing time varied from 1.25 to 2 hours. Catch per unit effort (CPUE) were expressed either in number or in weight per hour fishing. The small meshed codends without escapement window were chosen to ensure that the catches contained sufficient number of young fish in order to examine their distribution patterns. Fig. 3 illustrates the possible effect of an escapement window and a 125 mm codend on the observed length distributions.

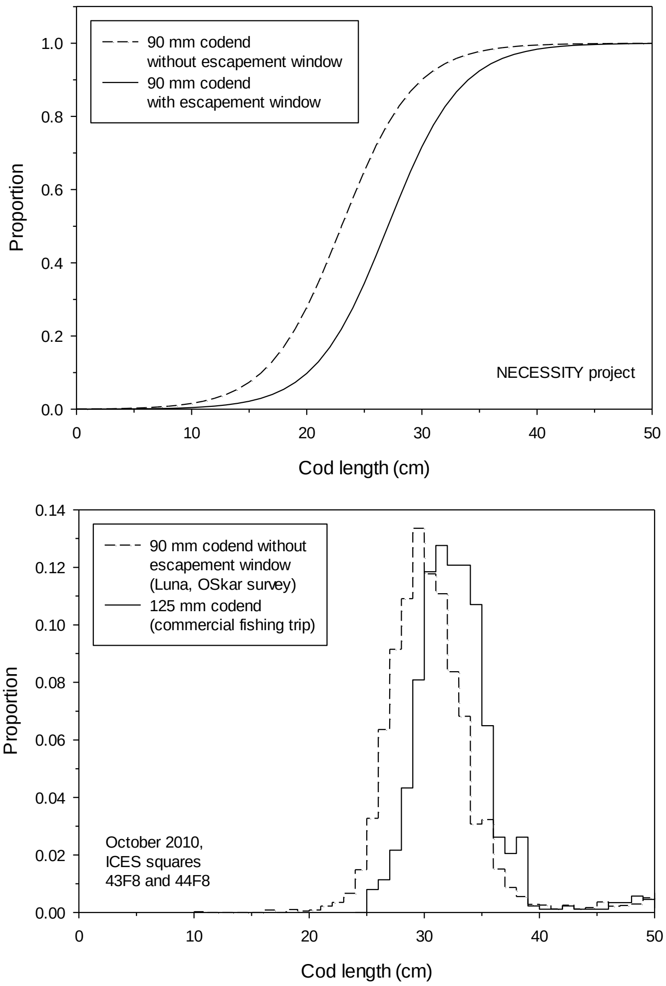


Figure 3. Proportion of cod retained in 90 mm meshsize codends with and without escapement window and comparison of length frequencies obtained with a 90 mm meshsize without escapement window and with a 125 mm meshsize codend.

The main survey area of the gillnetter consisted of 35 squares (5 ∗ 5 nmi) in the south-western part of the Skagerrak where the bottom conditions do not allow fishing with bottom trawls. Here, 15 squares were selected randomly prior to each survey and 3 additional squares were selected by the skipper during the survey. In addition to its main survey area, the gillnetter covered also a part of the north-eastern Skagerrak in June/July 2008 (Fig. 4). One to three sets (see below for the definition of sets) were made in each of these squares depending on the availability of different bottom conditions (sand bottom, stone bottom or ship wreck), and the precise positions of these sets were chosen by the skipper.

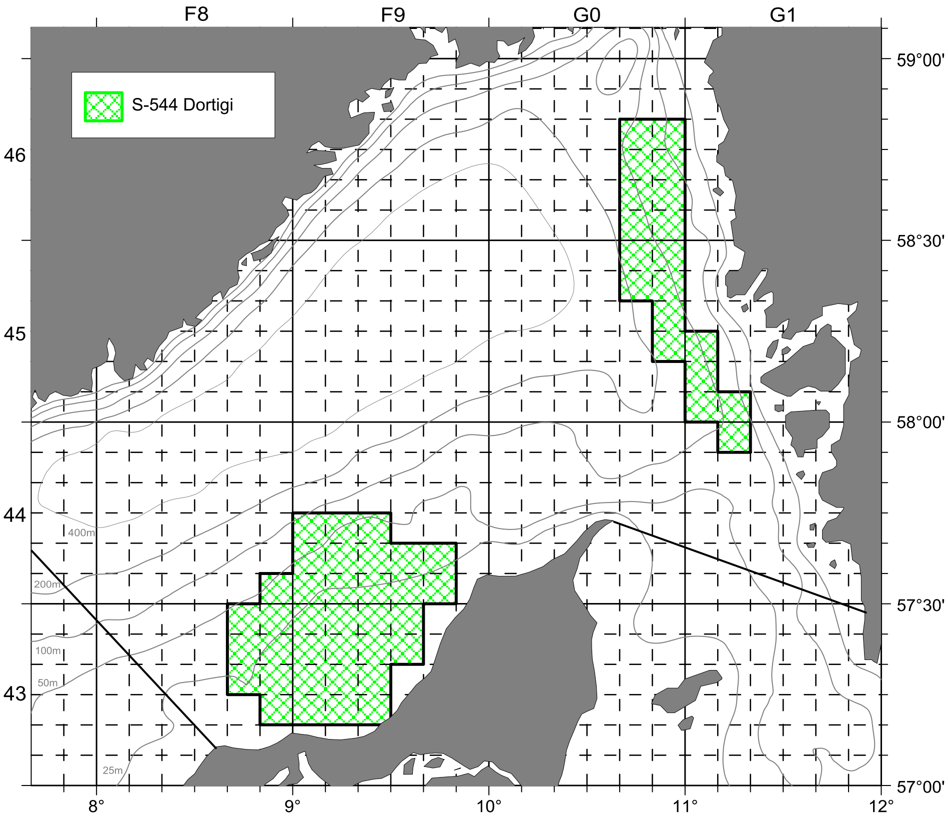


Figure 4. Survey area allocated to the gillnetter (north-eastern part covered only in June/July 2008).

The gillnetter used set of nets with a combination of three different mesh sizes (65, 75 and 85 mm half-meshes). Gillnet height was 2.5 m for the 65 mm nets and 2.2 m for the other two mesh sizes. The nets with the different meshsizes were set at the seabed in random order with usually the same portion of the different meshsizes at each station. The total number of nets that were set and the fishing time varied between stations (Fig. 5). Hence both, number of nets and soak time were considered to compute CPUE either in numbers or weight per net and hour of fishing.

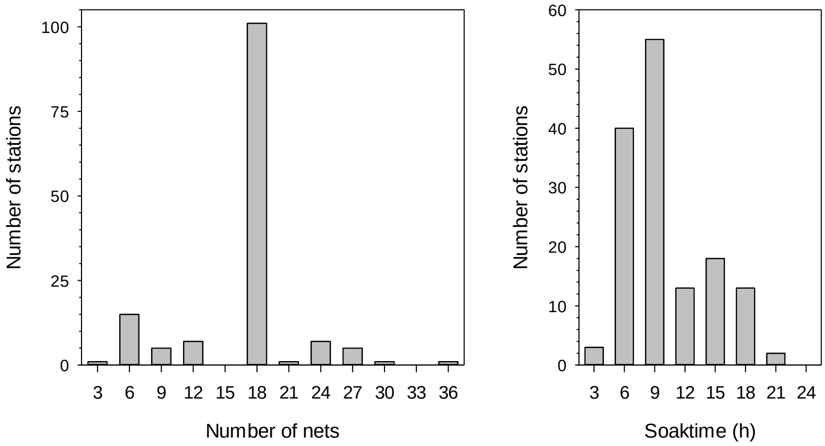


Figure 5. Variation of number of nets and soak time at gillnetter stations (total number of valid stations: 144).

Total catch (in weight) of commercial species retained for landing were recorded for each station. Length measurements were made for all sizes of cod, haddock, whiting, saithe and hake as well as for plaice and witch flounder in all surveys conducted in 2010 but not for plaice and witch flounder during the survey in June/July 2008 with the two trawlers.

All individuals were measured on the gillnetter, and catch in weight was computed using monthly length-weight relationships for cod, haddock, whiting, saithe and plaice and average length-weight relationships for the other species (Coull et al. 1989).

The catch of commercial species onboard the two trawlers was sorted into commercial grades, weighted and subsamples were taken for length measurements. The separation between catch retained for landing and discard did not always exactly follow the minimum landing size limits. Hence, catch weights below and above minimum landing size (MLS) were computed from the length frequencies raised to total catch as follows:

$$W_{<MLS} = (\sum_{i=1}^{i<MLS} n_i * \frac{w_i}{\sum n_i} * w_i) * W$$

and

$$W_{\geq MLS} = (\sum_{i \geq MLS}^{i} n_i * \frac{w_i}{\sum n_i} * w_i) * W$$

where n_i is the number of fish in length interval i, w_i is the corresponding individual weight from the length-weight relationship taken from Coull et al. (1989) and W is the measured total catch weight of a species at a given station.

Bottom temperature was recorded with HOBO data loggers during all trawl tracks and at about 50 % of the gillnetter stations on all surveys. The gillnetter measured also surface and bottom currents with an Acoustic Doppler Current Profiler (ADCP) during all four surveys and recorded turbidity in the bottom water at all stations during the three surveys in 2010. Turbidity was measured in Formazin Turbidity Units (FTU, http://www.optek.com). AIRMAR PB200 Weather Stations were used on the two trawlers during the three surveys in 2010 for continuous recording of meteorological data such as air temperature, wind speed and wind direction.

Environmental conditions

Wind speed at fishing locations covered by the two trawlers are shown for the survey in June/July in Fig. 6 and, together with air temperature, for the three surveys in February, May and October 2010 in Fig. 7a,b.

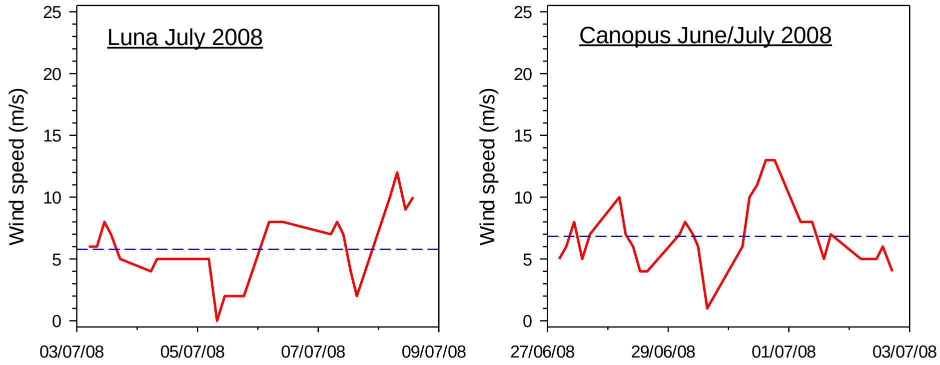


Figure 6. Wind speed recorded at trawl locations during June/July 2008 (dashed lines: survey mean).

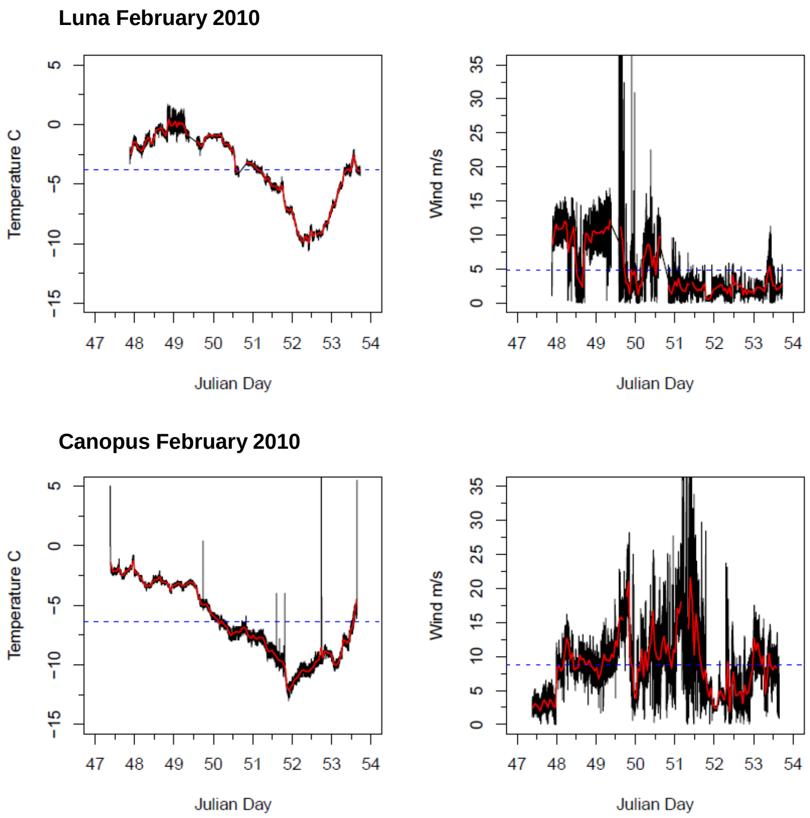


Figure 7a. Wind speed and air temperature recorded onboard the two trawlers during the survey in February 2010 (from AIRMAR PB200 weather stations, dashed lines: survey mean, red lines: 5 min moving average).

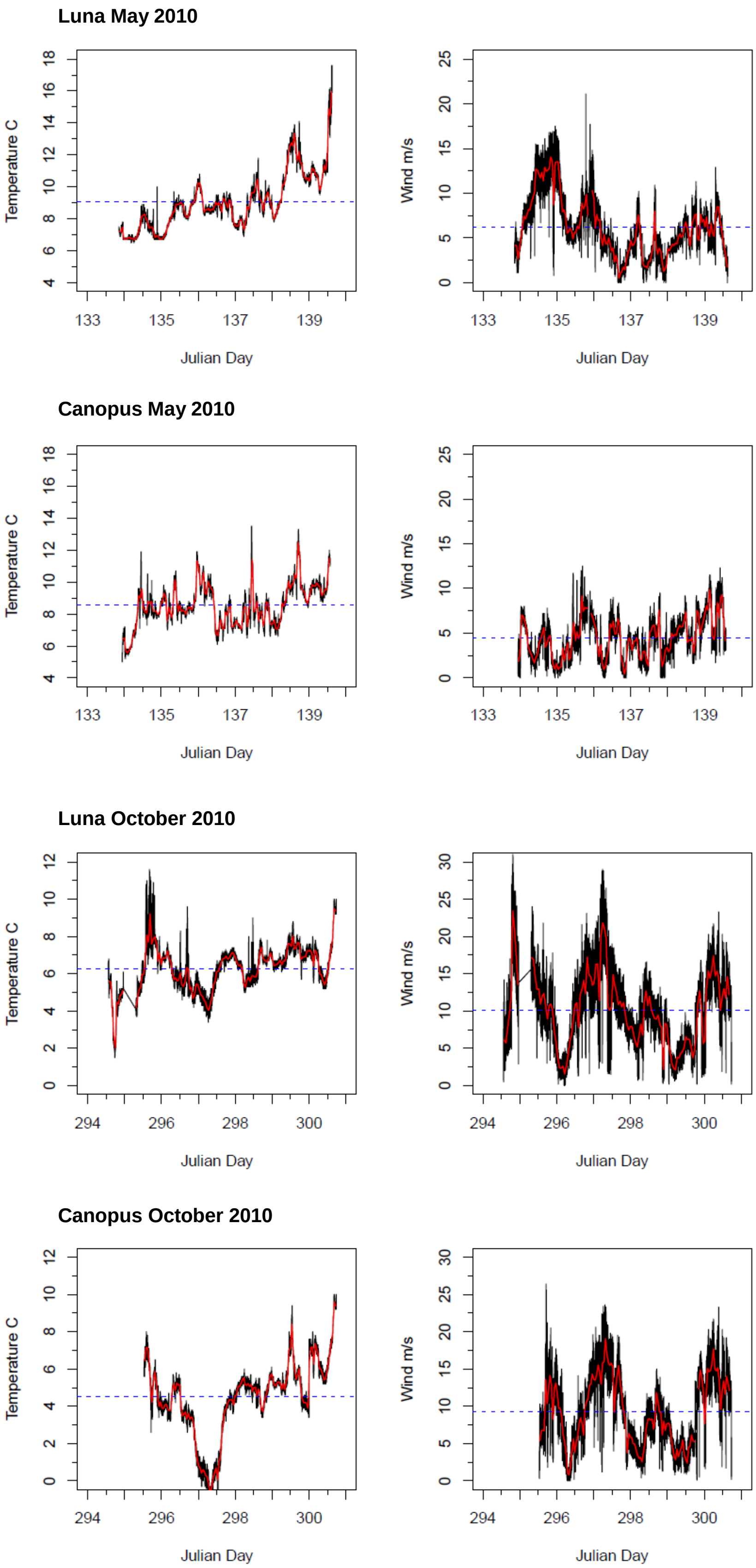


Figure 7b,. Wind speed and air temperature recorded onboard the two trawlers during the survey in May and October 2010 (from AIRMAR PB200 weather stations, dashed lines: survey mean, red lines: 5 min moving average).

Moderate wind conditions with average wind speeds of about 5 m/s and short periods at which the wind speed exceeded 10 m/s were encountered on both trawlers during the surveys in June/July 2008 and in May 2010 as well as with Luna in February 2010. The survey in October 2010 was characterized by rough wind conditions during longer periods for both vessels and wind speeds above 10 m/s prevailed also during several days in the western Skagerrak during the survey with Luna in February 2010. Cold conditions with air temperatures below 0 °C during the entire survey and about half of the survey period with air temperatures between -5 and -10 °C were faced in February 2010.

The wind conditions during the field work with the gillnetter are shown in Fig. 8. The surveys in February and October 2010 had to be shortened due to rough weather by two days each. Otherwise, the sampling was conducted at moderate conditions except for the end of the survey in May 2010 where wind speeds of 12 m/s came close to the limit on which work would no longer had been safe considering the small size of the vessel.

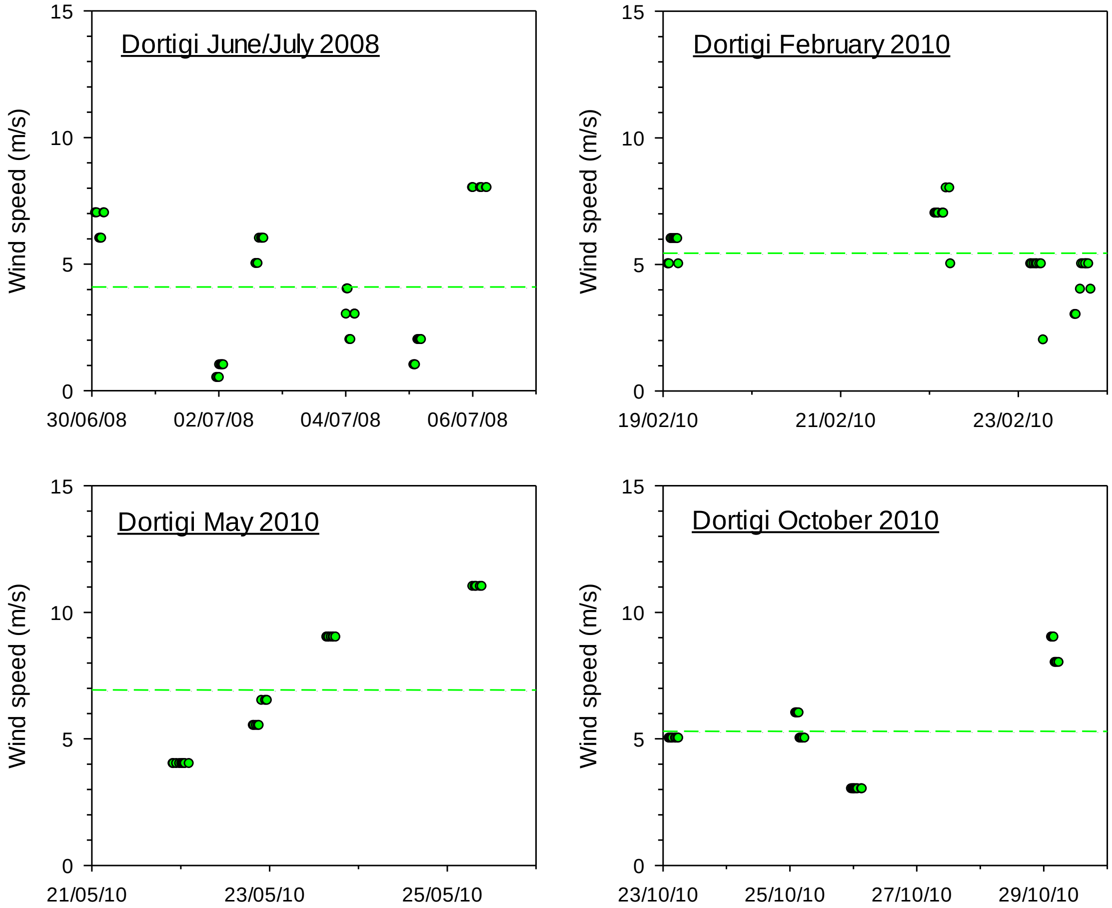


Figure 8. Wind speed recorded at fishing locations with the gillnetter during the four OSkar surveys (dashed lines: survey mean).

Bottom currents speed at gillnet stations in the southwestern Skagerrak were always below 0.9 knots (0.46 m/s). During the first three surveys, bottom current directions varied and current speed was generally below 0.2 m/s whereas current direction was more uniform and current speeds above 0.2 m/s were recorded on most of the stations in October 2010 (Fig. 9). In general, highest bottom current speed was observed on smooth (sand) bottom stations, and during all surveys bottom current direction across the depth contours, i.e. from the coast towards deeper water, dominated.

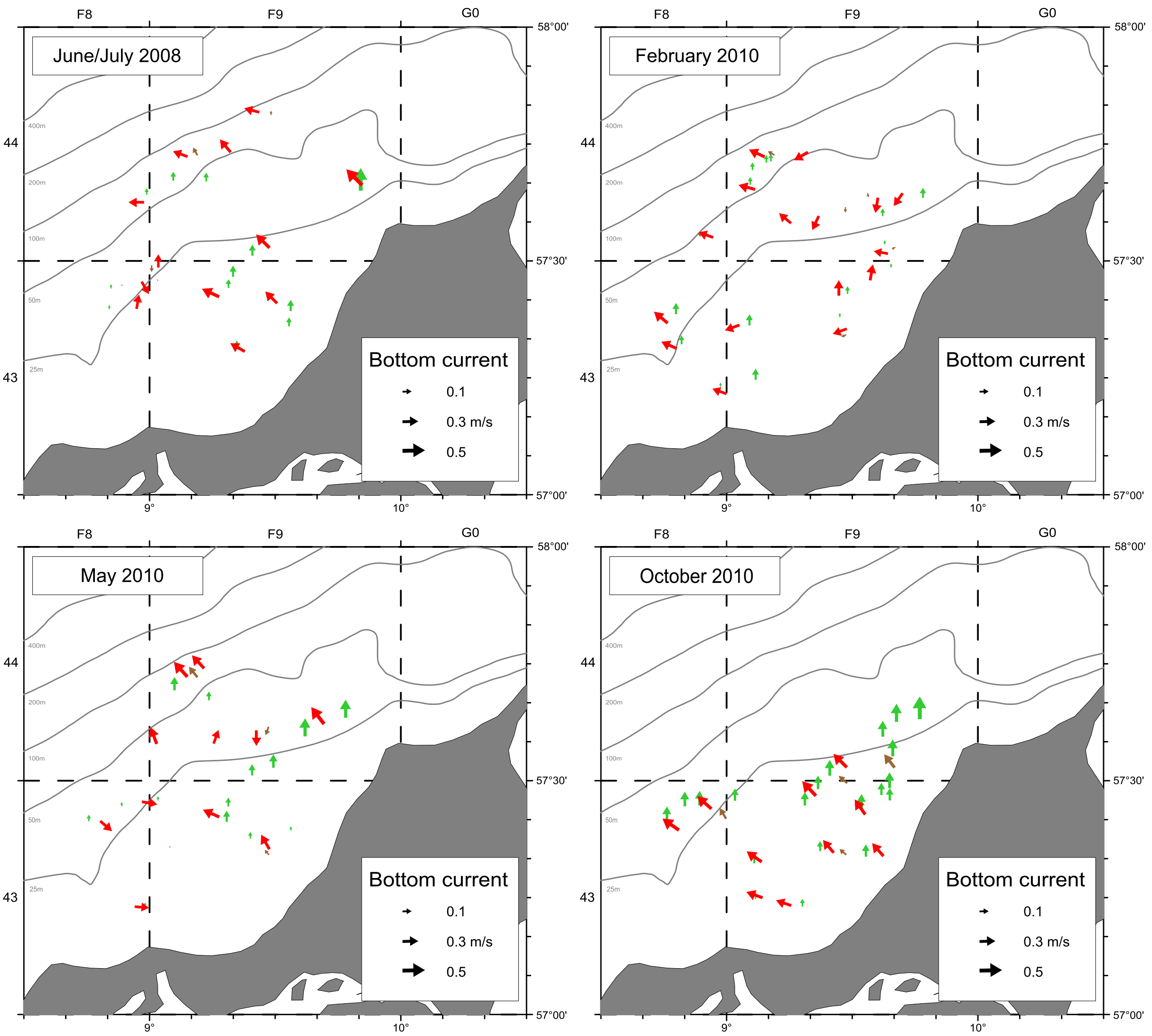


Figure 9. Bottom currents measured at fishing locations during the four OSkar surveys with the gillnetter in the southwestern Skagerrak (red arrows: sand bottom, green arrows: stone bottom, brown arrows: ship wrecks).

Turbidity measured at gillnet stations in the southwestern Skagerrak was on a similar level in February and May 2010 but larger values and considerable higher variations between stations were found during the surveys in October 2010 (Fig. 10). On average, turbidity recorded at ship wrecks was lower than for the two other bottom types, and there was no difference in turbidity between sand and stone bottom. No indication was found that turbidity was related to the actual wind speed or bottom current speed (Fig. 11).

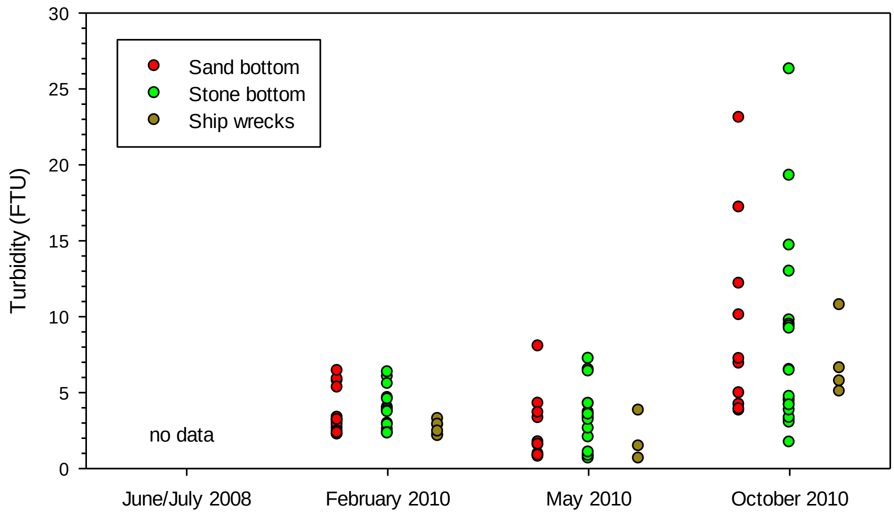


Figure 10. Turbidity measured at fishing locations during the three OSkar surveys in 2010 with the gillnetter in the southwestern Skagerrak (red arrows: sand bottom, green arrows: stone bottom, brown arrows: ship wrecks).

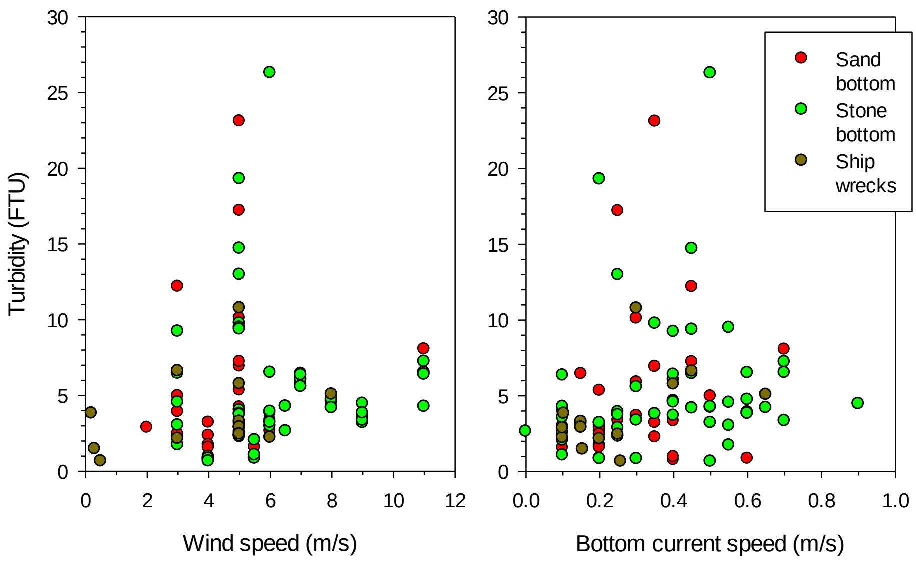


Figure 11. Turbidity measured at fishing locations during the three OSkar surveys in 2010 with the gillnetter in the southwestern Skagerrak in relation to wind speed and bottom current speed (red arrows: sand bottom, green arrows: stone bottom, brown arrows: ship wrecks).

Bottom temperatures recorded by the two trawler and the gillnetter during the four surveys are shown in Fig. 12. Temperatures above 13 °C were observed in the south-western part of the survey area at depths below 25 m in June/July 2008. An area of cold water with temperatures below 5 °C extended across all depth contours in February 2010 in the western Skagerrak. The later surveys in 2010 illustrate the seasonal warming with highest temperature in the shallow part in the western Skagerrak and the coldest water at depth below 200 m.

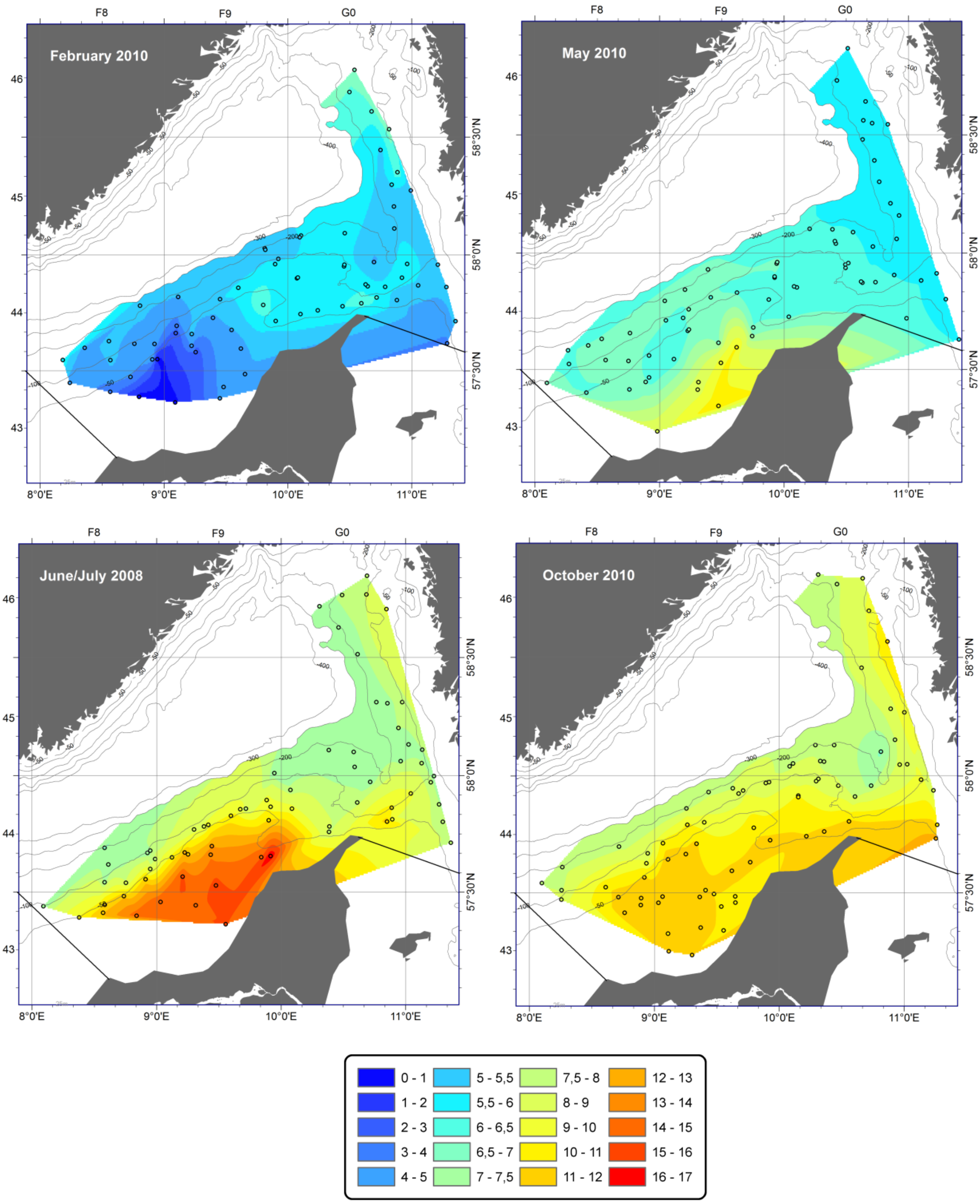


Figure 12. Bottom temperature °C measured during the four OSkar surveys (data from all three vessels combined, maps produced with ArcGis using 'Natural neighbor' interpolation).

All measured bottom temperatures were plotted against the average depth (Fig. 13) and ranged from 0.6° C at 27 m in 1st quarter to 16.9° C at 28 m in the 3rd quarter. Not surprisingly are these extreme temperatures measured at the shallow station and differ considerably from the stations at depths larger than 100 m.

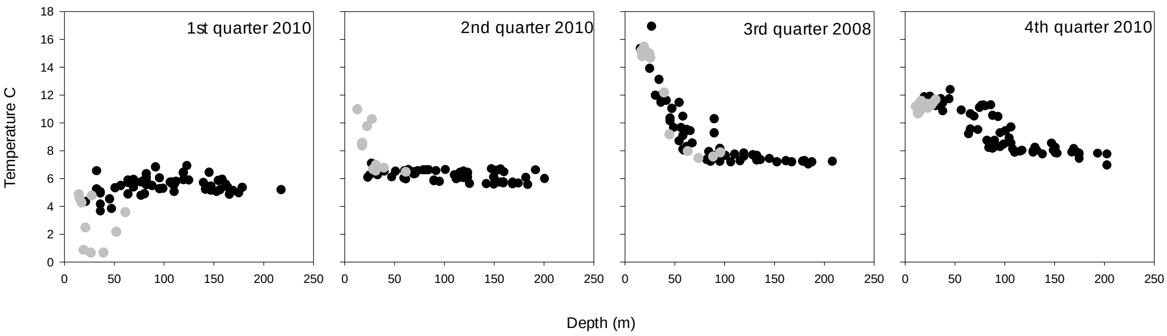


Figure 13. Average bottom temperatures (° C) from each station plotted against the average depth (m) on the respective stations, all four OSkar surveys (grey circles: gillnetter measurements, black circles: trawler measurements).

The bottom temperature in the 1st quarter trawl survey area ranged from 2° C to 7° C with the lowest temperature in shallow water, especially in the south-western part of the survey area that was influenced by intrusion of cold surface water from the North Sea (Fig. 12). The overall temperature trend in the trawled regions in the 2nd quarter was a decrease from 7° C to 5° C with increasing depth (Fig. 13). This depth trend was superimposed by a gradient of decreasing temperature from southwest to northeast in the total survey area due to intrusion of 10° C surface water from the North Sea (Fig. 12). The overall temperature trend in the survey area in the 3rd quarter was a decrease from 17° C to 7° C with increasing depth (Fig. 13). This depth trend was strongly superimposed by a gradient of decreasing temperature from southwest to northeast due to intrusion of warm surface water from the North Sea (Fig. 12). The temperature decreased with increasing depth from 12° C to 7° C in the 4th quarter (Fig. 13). Compared to quarter 3, the temperatures in shallow water were lower and evenly distributed within the entire survey area (Fig. 12), whereas the temperatures between 100 m and 200 m were higher in the 4th quarter than in the 3rd quarter (Fig. 13).

Trawl calibration and conversion of catch rates

Both trawlers used TV-4 trawls but the size and the rigging of the trawl differed between them (Tab. 2) to allow best performance according to the different vessel specification e.g. concerning vessel size, horse power and the prevailing bottom conditions in the allocated main survey area. These were soft mud bottom in the eastern Skagerrak for Canopus requiring a light rigging and smooth to rough sand bottom in the western Skagerrak for Luna requiring a more robust rigging.

Table 2. Trawl specifications for Canopus and Luna.

	Canopus	Luna	
Total trawl length	56	74	m
Length of groundrope	52.3	59	m
Vertical opening	3	4	m
Mesh size in cod end	90	90	mm
Mesh size in upper wing	100	160	mm
Mesh size in lower wing	100	100	mm
Diameter of groundrope	4	5	cm
Diameter of rubber disks in central section	none	15	cm
Diameter of rubber disks in wing section	none	10	cm
Sweep length	96	162	m
Area of doors	2.82	3.73	m^2
Weight of doors	450	850	kg

The difference in trawl size and rigging made calibration experiments necessary in order to obtain consistent data series for the entire study area. The trawl calibration was done based on side-by-side trawling during the surveys in February, May and October 2010 at 5 to 6 different stations during each of the three surveys. The sampling sites were located in the border area allocated to the two vessels at depths between 50 and 200 m (Fig. 14).

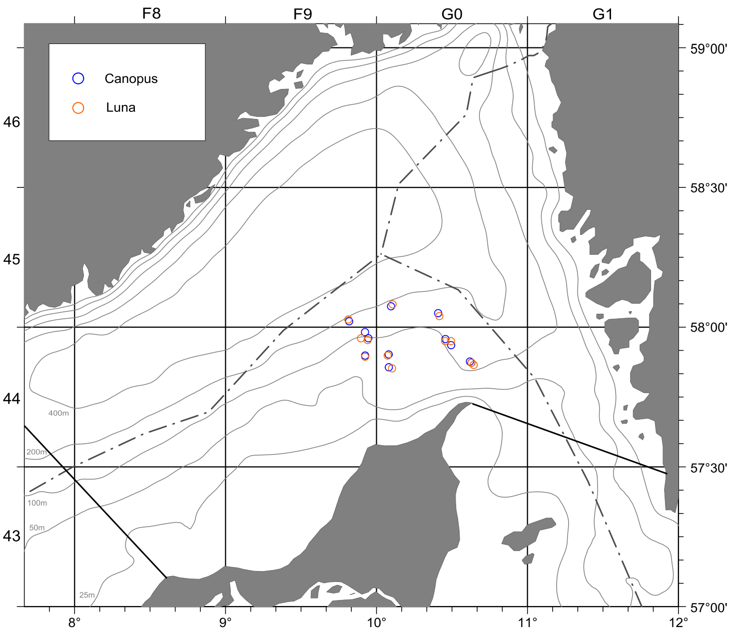


Figure 14. Locations of the trawl calibration experiments (February, May and October 2010).

As expected from the different dimensions of the trawls, the door spread on stations conducted with Canopus was consistently lower than on the corresponding stations conducted with Luna (Fig. 15). The average value for the ratio of door spread amounted to 1.47 (Luna vs. Canopus). If door spread would have been the only factor relevant for the efficiency of the trawl, catch rates from Canopus could have been multiplied by this value to obtain catch rates which are comparable to those from Luna. Due to the longer sweeps used on Luna, the effect of the larger door spread is not directly transferable to wing spread, which was not measured. A conversion factor being somewhat lower than the average door spread ratio is therefore more likely.

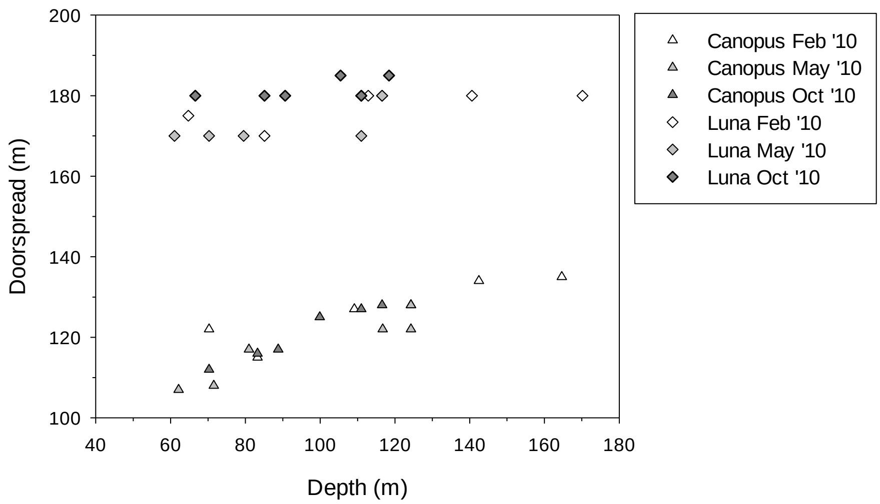


Figure 15. Door spread for Canopus and Luna at station depth as measured during the calibration experiments (17 stations in total).

Comparisons of catch rates obtained with the two vessels for various species and size groups (Figs 16 a-c) showed that specific conversions factors rather than one single value were appropriate for the transformation of catches.

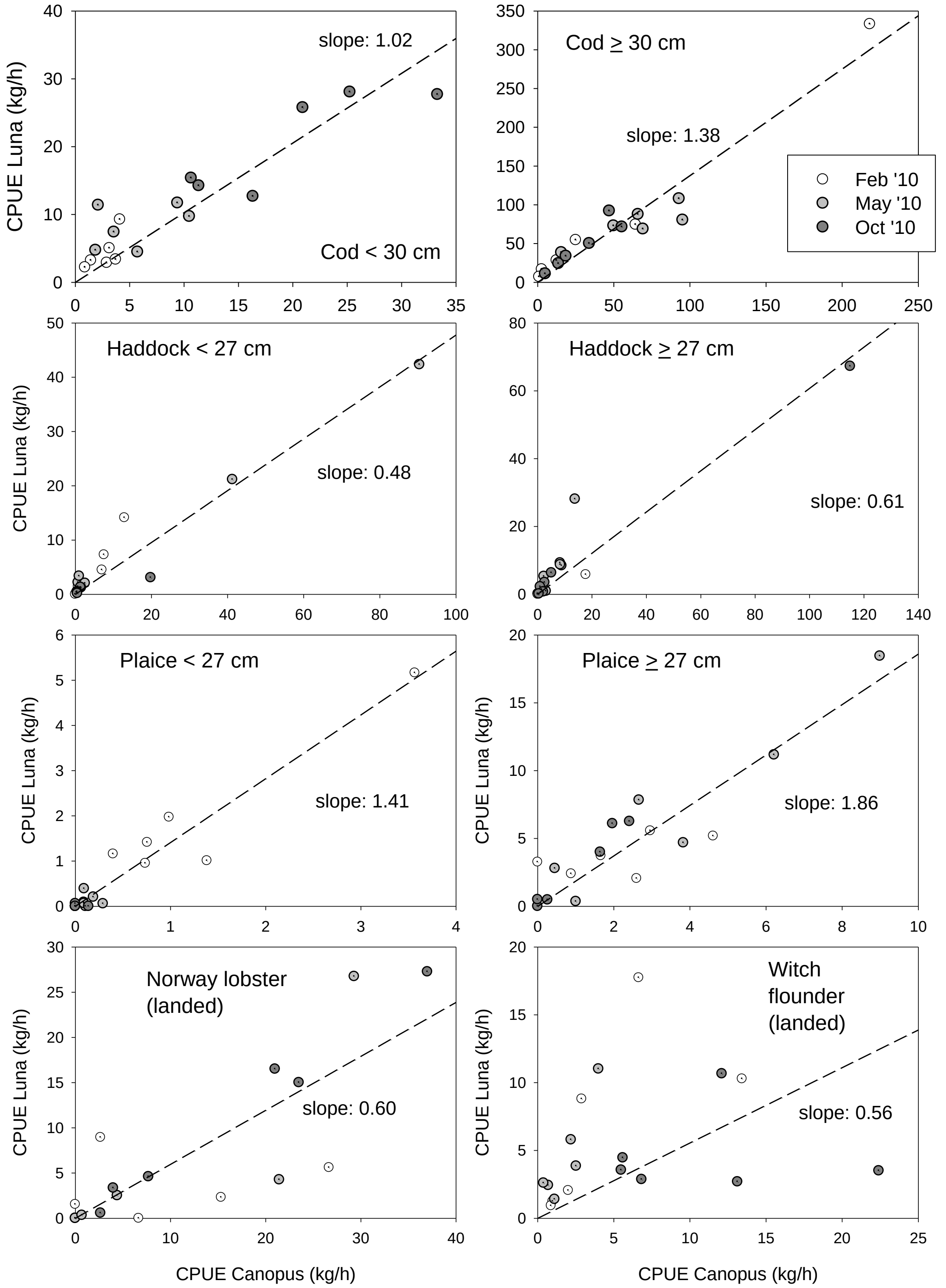


Figure 16a. Comparison of catch rates in kg/h for cod, haddock and plaice below and above minimum landing size and the landed catch of Norway lobster and witch flounder (dashed lines refer to regressions y = a ∗ x, a: slope)

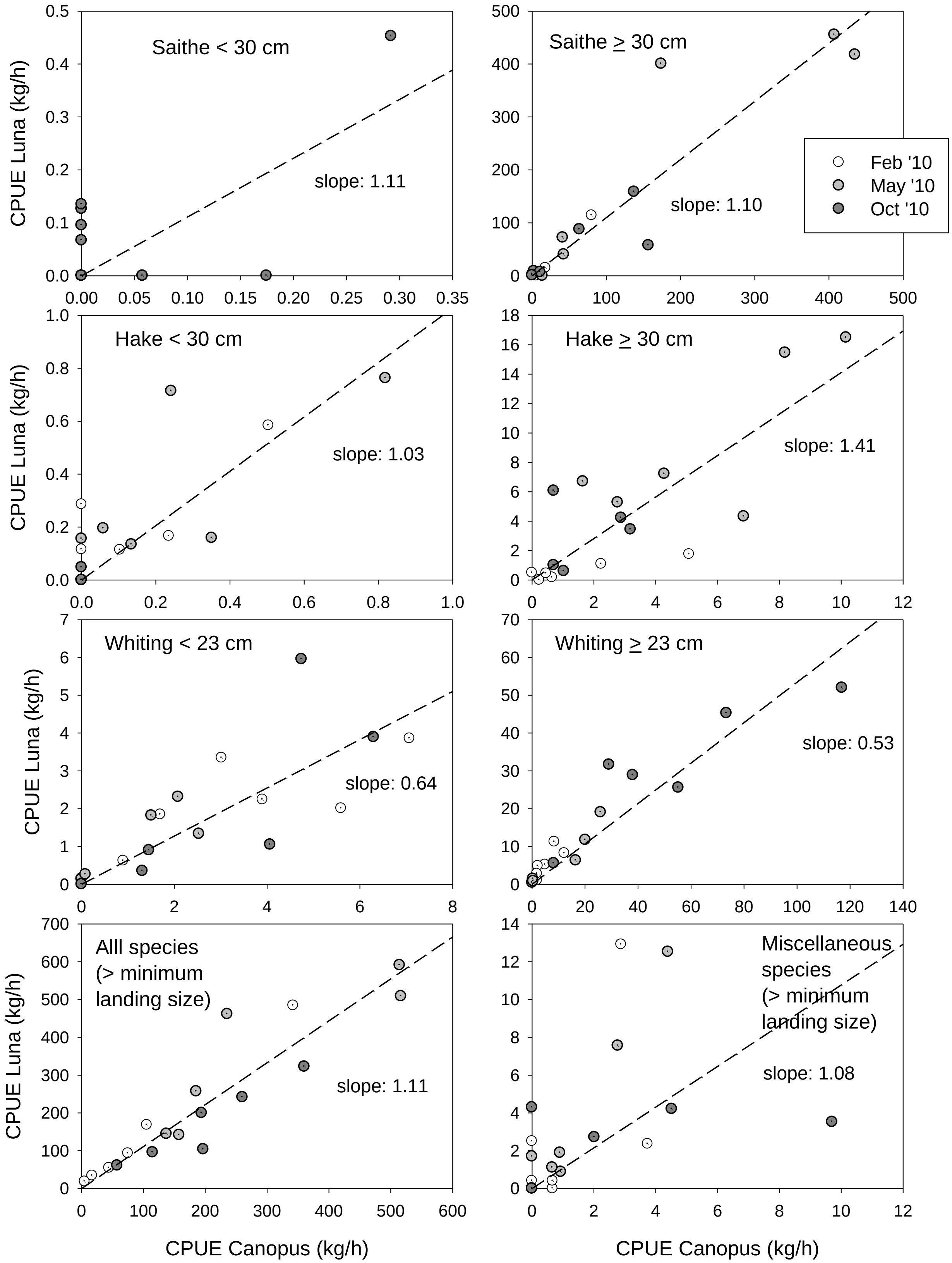


Figure 16b. Comparison of catch rates in kg/h for saithe, hake and whiting below and above minimum landing size and for all species combined as well as miscellaneous species (all other than the species presented in detail) above minimum landing size (dashed lines refer to regressions. y = a ∗ x, a: slope).

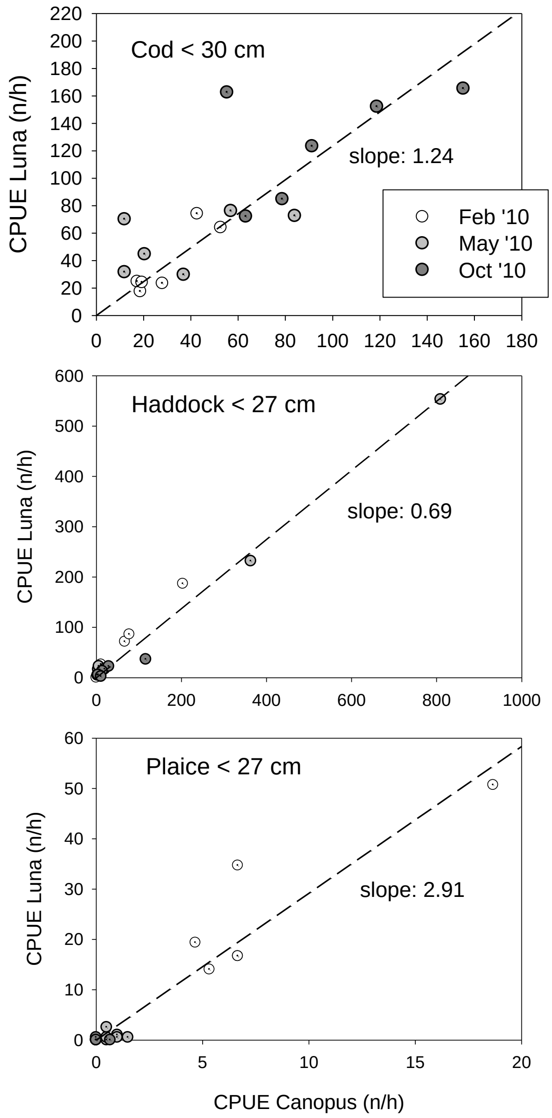


Figure16c. Comparison of catch rates in n/h for cod, haddock and plaice below minimum landing size (dashed lines refer to regressions y = a ∗ x, a: slope).

High variability in the catch rates were observed for Norway lobster and witch flounder, saithe below minimum landing size was absent in most of the stations. Despite the low number of observations, regression analyses yielded acceptable results for the other species and size groups. The intercepts in the regressions were always not significant and hence the slope of the regression lines represents the conversion factors to raise Canopus catch rates to Luna standards. The conversion factors differed considerably between species and size groups, and considering the much wider door spread for Luna, the values far below 1 for haddock and whiting were surprising. However, the larger mesh size in the upper wings may allow these two species to escape to a larger extent from the Luna trawl than from the Canopus trawl. The relative low efficiency of the Canopus for catching plaice is more difficult to explain but may be related to the bottom conditions in the area in which the calibration experiments were conducted. Here the heavier ground rope used on Luna could have resulted in higher catch rates than the light ground rope from Canopus being most efficient on soft mud bottom where Luna could not fish at all.

Distribution of important commercial species

Geographical distribution of target species below and above minimum landing size

The geographical distributions of catch rates recorded with the two trawlers for saithe above minimum landing size and of haddock and cod below and above minimum landings size for the four sampling periods are shown in Figs. 16 to 19. Here, catch rates were expressed either in numbers per hour fishing (cod and haddock below minimum landing size) or in kg per hour fishing (saithe, haddock and cod above minimum landing size). The catch rates from both trawlers were combined using the conversion factors presented in Figure 16.

The catch rates of saithe above minimum landing size (30 cm) were highly scattered in June/July 2008, May 2010 and October 2010. In these three surveys, areas in which high densities of saithe were recorded differed considerably but were usually located at depths of more than 100 m whereas in February 2010 only few saithe were caught at all.

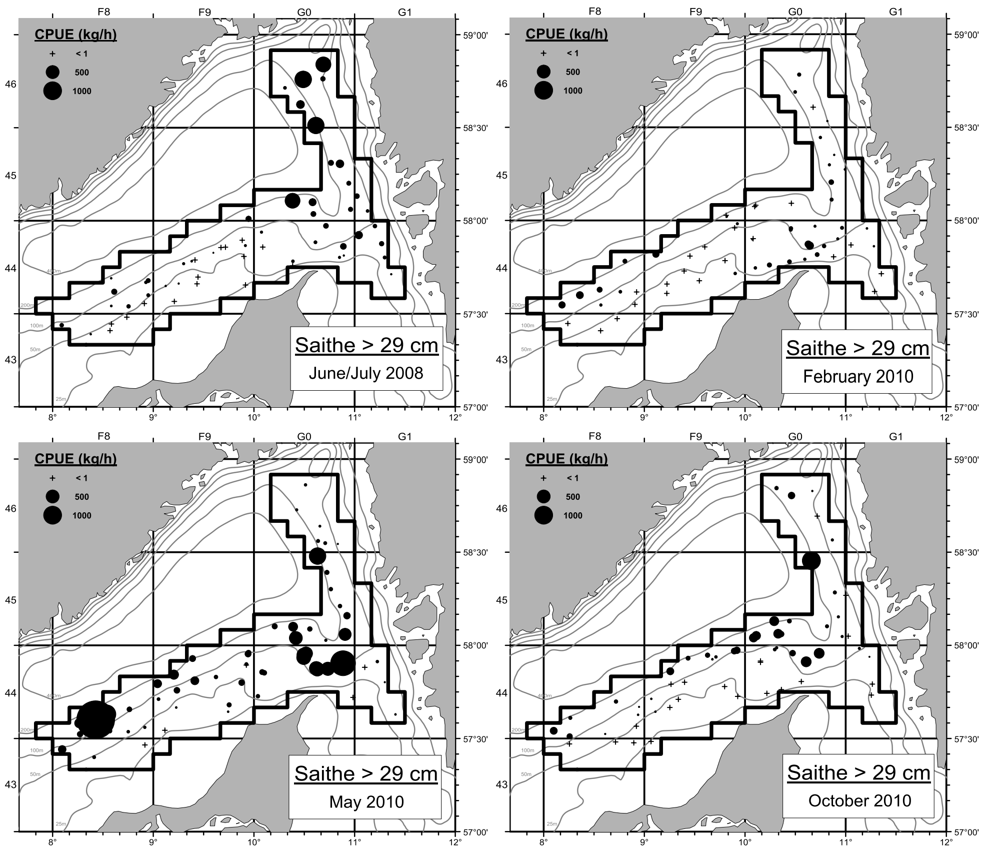


Figure 17. Geographical distribution of trawler catch rates of saithe above minimum landing size during the four OSkar surveys.

Small haddock was mainly found in the western part of the survey area at depths between 50 and 100 m except for the survey in February 2010 where high densities were also found in the eastern Skagerrak and the distribution was limited to depth larger than 100 m in the westernmost part of the survey area (Fig. 18). Densities of haddock above minimum landing size (27 cm) were low in the first three survey whereas high concentrations were observed between 50 and 100 m depth in the western Skagerrak and in particular close to 50 m depth contour west of Skagen (Fig. 18).

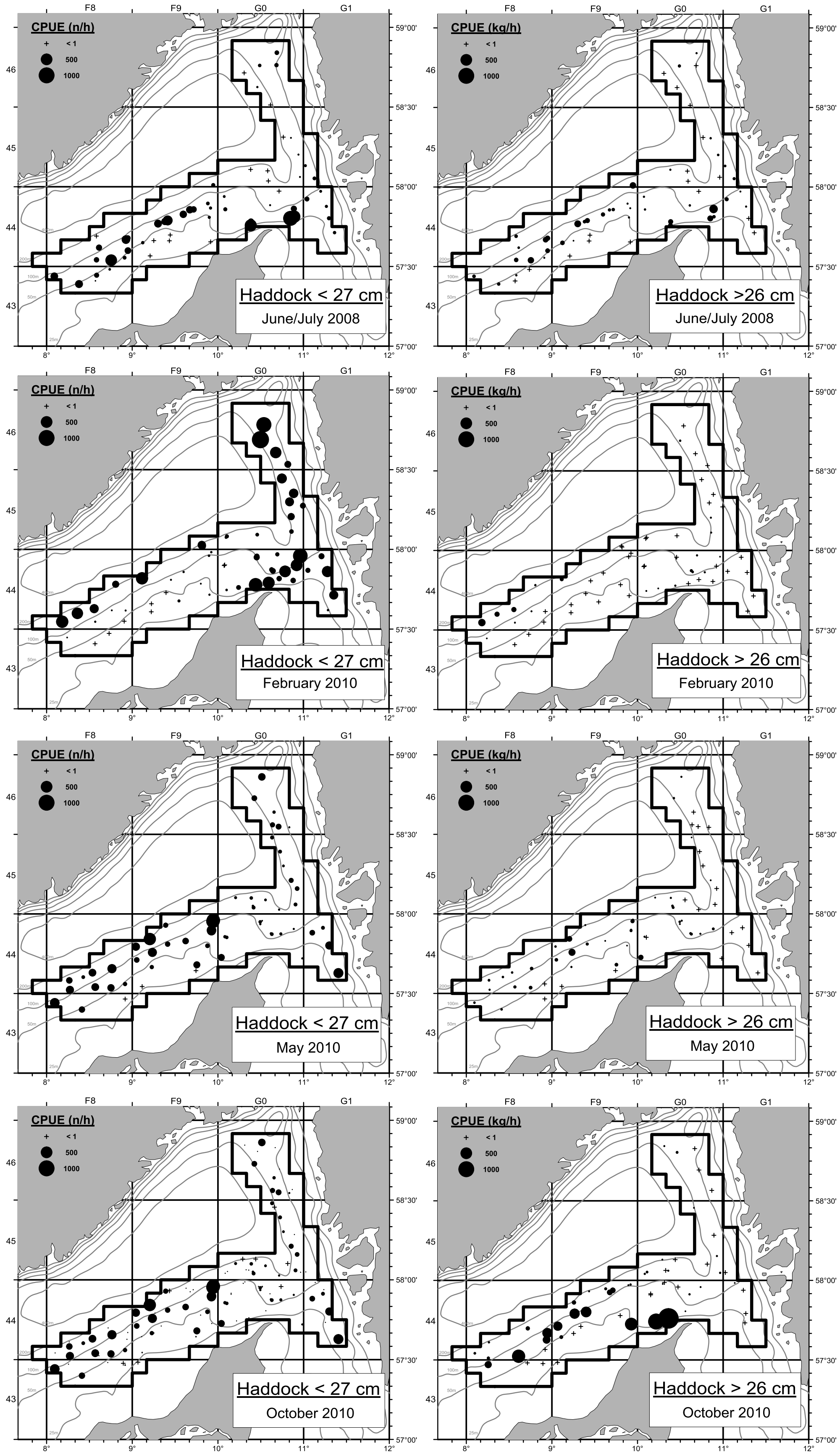


Figure 18. Geographical distribution of trawler catch rates of haddock below (left column) and above (right column) minimum landing size during the four OSkar surveys.

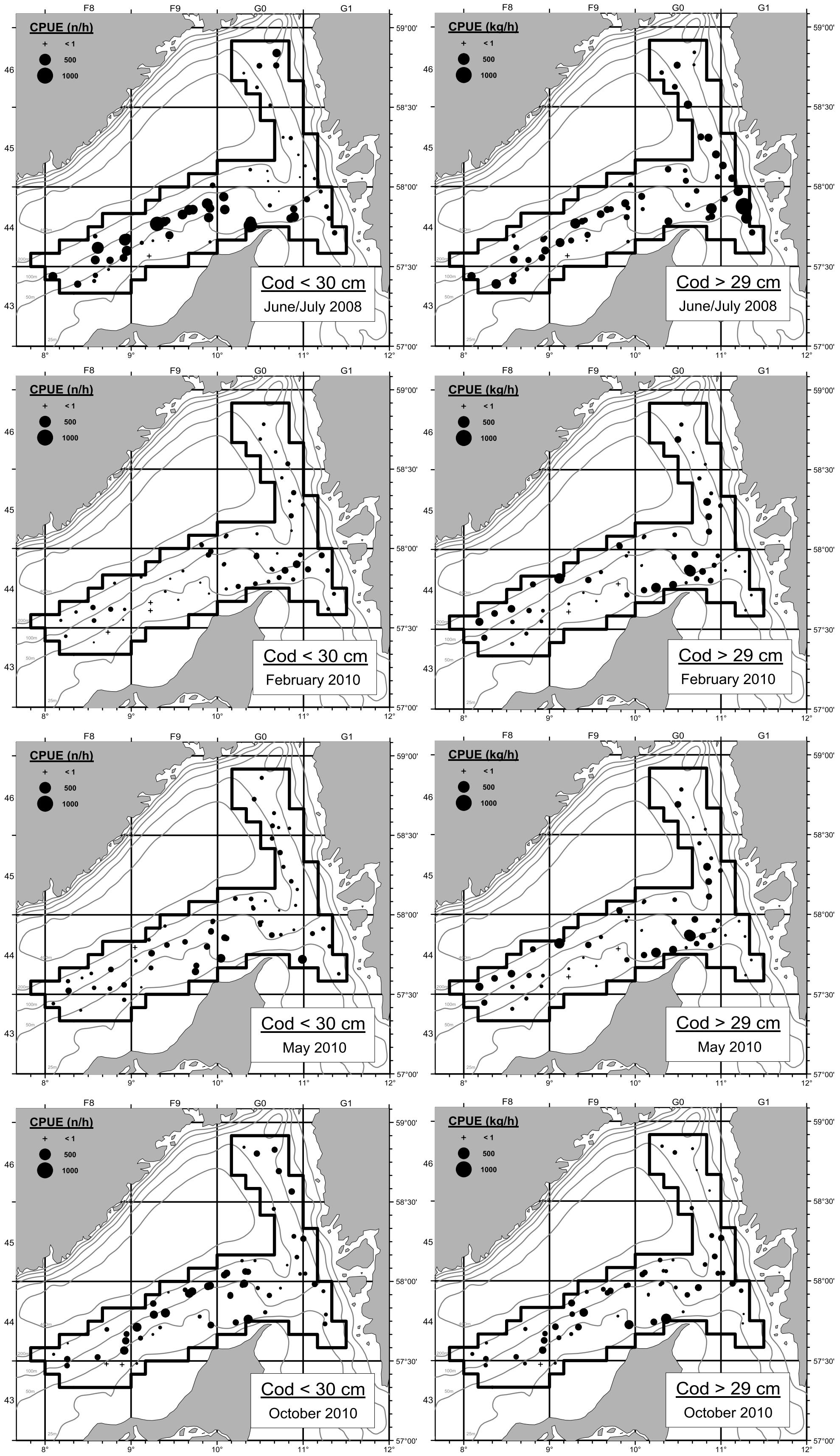


Figure 19. Geographical distribution of trawler catch rates of cod below (left column) and above (right column) minimum landing size during the four OSkar surveys.

Average catch rates of small cod were highest in the western Skagerrak between 50 and 100 m depth June/July 2008 (Fig. 19). Similar distribution patterns were observed in May and October 2010 but at lower levels of abundance whereas the small cod were almost restricted to an area northeast of Skagen. Cod above minimum landing size (30 cm) showed a wide overlap with the undersized cod for all sampling periods (Fig. 19).

The geographical distributions of catch rates recorded with the two trawlers for plaice above minimum landing size for the three surveys conducted in 2010 are shown in Fig. 20. Small plaice were found in the eastern Skagerrak during all the three surveys and high densities were additionally recorded in the western part of the survey area in February whereas plaice above minimum landing size (27 cm) were caught in noteworthy amounts only during May in the southeastern Skagerrak.

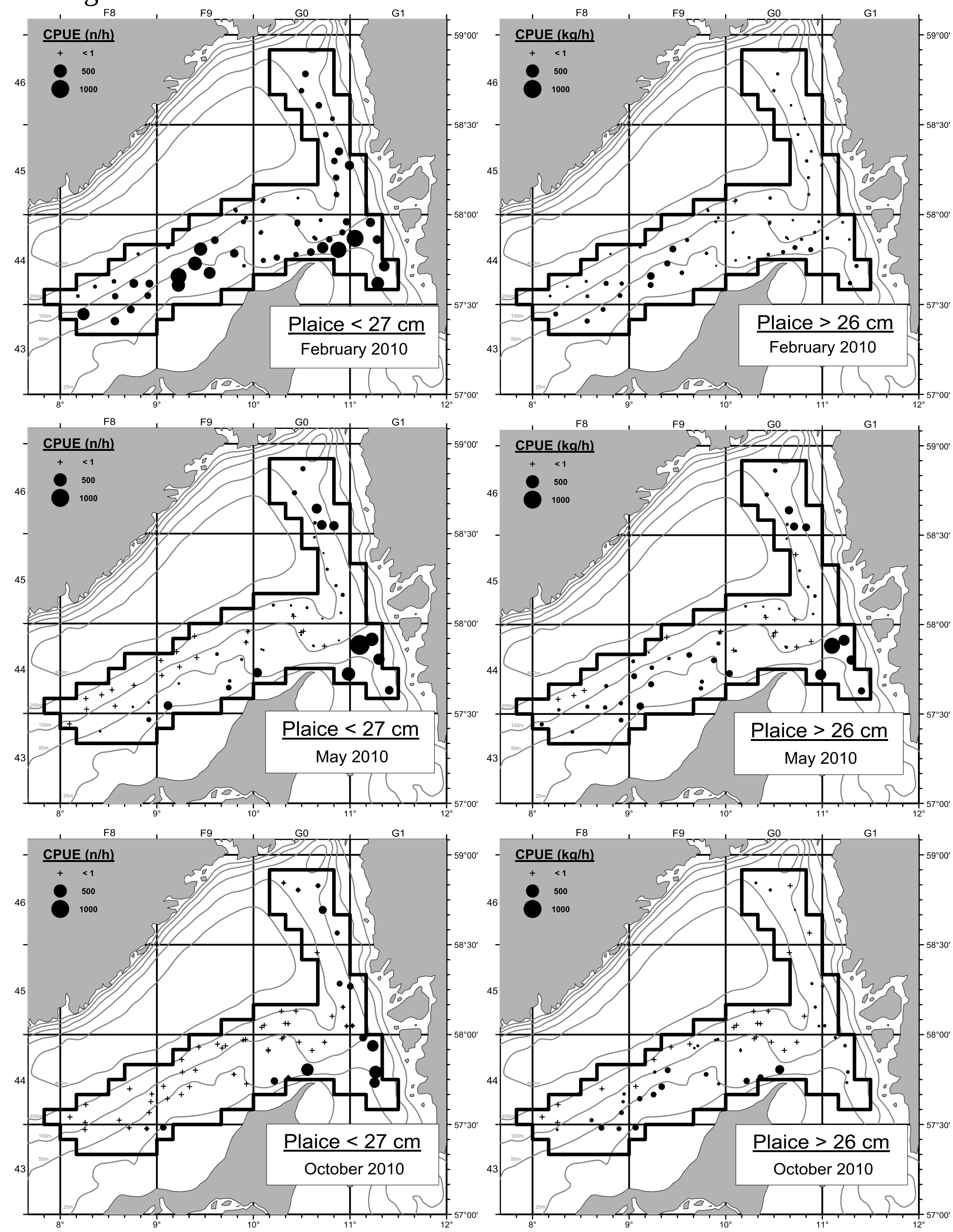


Figure 20. Geographical distribution of trawler catch rates of plaice below (left column) and above (right column) minimum landing size during the three OSkar surveys conducted in 2010.

The geographical distribution of catch rates of Norway lobster retained for landing from the three surveys in 2010 (Fig. 21) indicated that the spatial overlap with undersized cod (Fig. 19) was restricted to a small area between 100 and 200 m depth in October 2010 while a more extended overlap with small haddock (Fig. 18) was observed for all survey periods.

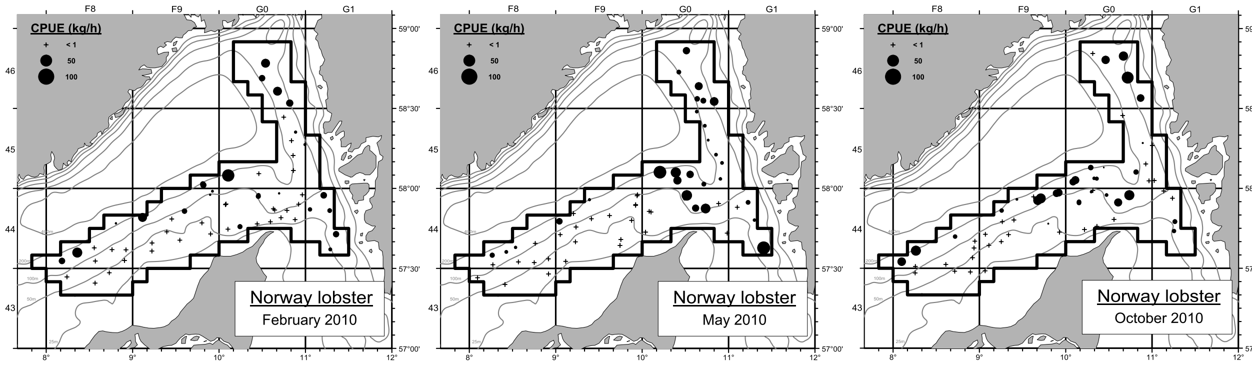


Figure 21. Geographical distribution of trawler catch rates of Norway lobster retained for landing during the three OSkar surveys conducted in 2010.

The area covered by the two trawlers did not include depths of less than 25 m due to unsuitable bottom conditions there. In contrast to the trawlers, the gillnetter fished preferably in this area and covered different bottom types i.e. smooth sand bottom, rough stone bottom and ship wrecks. Catch rates of cod were generally higher on rough bottom and at ships wreck than on sand bottom (Fig. 22).

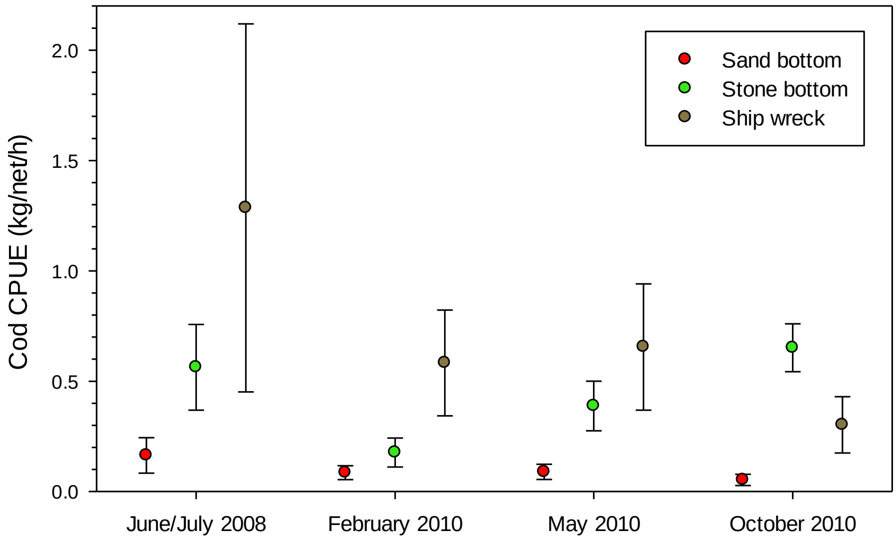


Figure 22. Average gillnetter catch rates of cod in relation to bottom type during the four OSkar surveys (mean ± standard error).

Considerable concentrations of cod on stone bottom in the shallow (< 25 m) water were found in October 2010 but not at the other survey dates (Fig. 23).

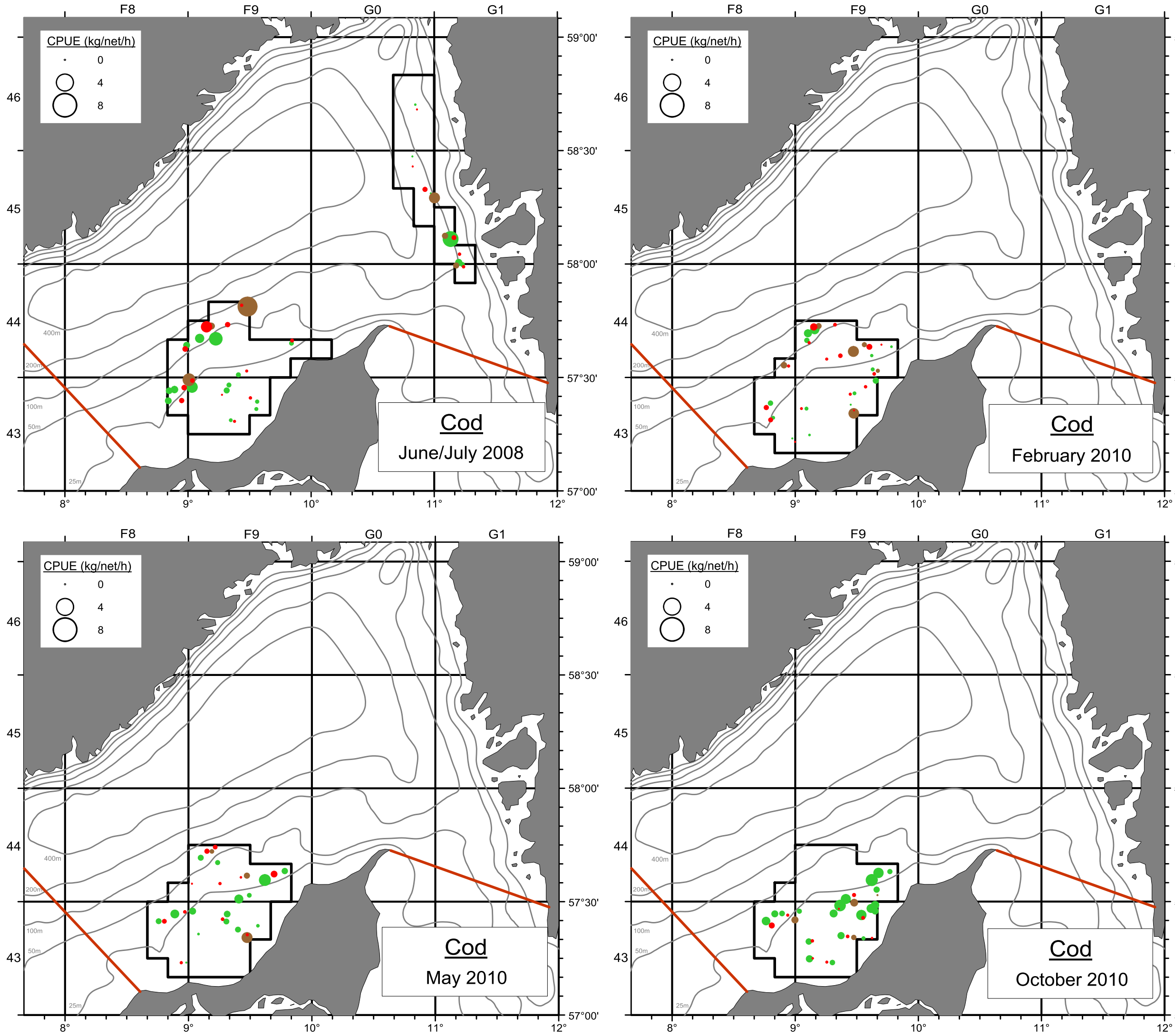


Figure 23. Geographical distribution of gillnetter catch rates of cod (kg/net/h) in relation to bottom type during the four OSkar surveys (red: sand bottom, green: stone bottom, brown: ship wreck).

After the last survey in October 2010, the gillnetter continued using the same gillnets during commercial fishing trips for 7 additional days. The fishing under commercial conditions was conducted in ICES squares 43F9 and 44F9, and all sets were done on stone bottom. Soak time range from 6 to 17 h and the number of nets used on each fishing day was 190. In total, 93 % of the catch in weight taken during the 7 fishing days was cod. The average CPUE of cod for these fishing trips are plotted in Fig. 24 showing fairly stable catch rates, which were on average at the similar level as recorded during the preceded OSkar survey.

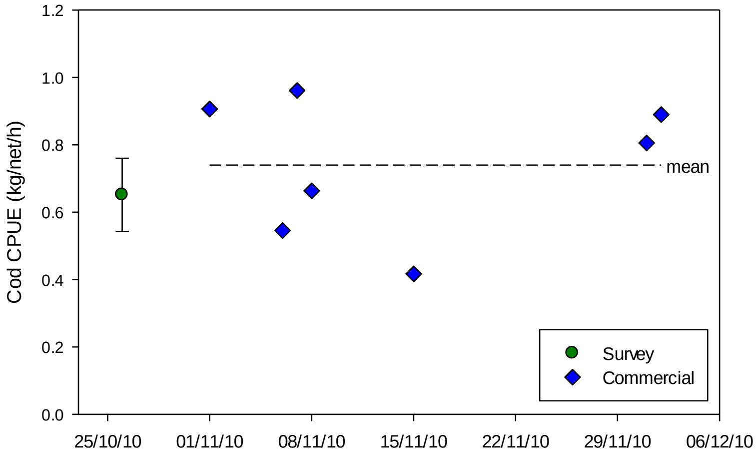


Figure 24. Survey CPUE for cod on stone bottom (mean ± standard error) in October 2010 and CPUE for cod on stone bottom using the same type of gillnets during commercial fishing trips in November/December 2010 in the southwestern Skagerrak.

Cluster analysis on catch compositions in relation to geographical distribution

To identify potential patterns in the catch composition cluster analysis was made for each survey. The data used was CPUE values for each station, for selected species converted to Luna values. Only data from the trawl survey is included as no clustering was found when analyzing the gillnet data alone. The selected species included in all four analysis were the gadoids cod, haddock and saithe and for the tree surveys in 2010 (1Q, 2Q and 4Q) also plaice and landed Norway lobster was included. For the analysis, all species except saithe and Norway lobster were split into two groups: below and above minimum landing size.

Method

The cluster analysis on group average was performed using the program PRIMER 6, log(x+1) treating the data before running a Bray Curtis similarity matrix for resemblance. The analysis was run between samples using 999 simulation permutations and a significance level of 5%. In order to characterize each cluster a SIMPER one-way analysis was run using the Bray Curtis similarity matrix and a cut off for low contributions at 75%. The contributing species to each cluster and their contributions can be seen in Table 3-6.

Results

Letters in parentheses indicate the cluster groups in the quarter of the year concerned.

Table 3. Description of the 1st quarter clusters, number of stations, average similarity within the group, species contribution and cumulative contribution.

1st quarter Group	No of stations in group	Average similarity within the group	Species	Contribution %	Cum. %
A	1	-	–	-	-
B	1	-	-	-	-
C	16	73,31	Plaice>=27cm	40,58	40,58
			Plaice<27cm	30,47	71,04
			Cod>=30cm	23,54	94,58
D	1	-	-	-	-
E	4	88,76	Cod>=30cm	23,85	23,85
			Saithe>=30cm	20,39	44,24
			Haddock>=27cm	17,90	62,15
			Haddock<27cm	16,67	78,82
F	1	-	-	-	-
G	2	93,95	Cod>=30cm	34,60	34,60
			Saithe>=30cm	27,21	61,81
			Haddock>=27cm	11,61	73,41
			Haddock<27cm	8,94	82,35
H	18	80,65	Cod>=30cm	29,29	29,29
			Saithe>=30cm	17,63	46,92
			Plaice>=27cm	15,28	62,20
			Plaice<27cm	11,29	73,50
			Haddock<27cm	11,22	84,82
I	10	79,45	Cod>=30cm	23,02	23,02
			Nephrops	16,77	39,79
			Haddock<27cm	15,78	55,58
			Plaice>=27cm	13,63	69,21
			Cod<30cm	12,53	81,74
J	4	75,33	Cod>=30cm	30,22	30,22
			Plaice>=27cm	23,74	53,96
			Cod<30cm	17,20	71,15
			Plaice<27cm	13,62	84,78

Quarter 1 (Fig. 25.A & Tab.3)

Plaice and large cod dominate the catch composition in shallow water (50-100 m) over the entire survey area (c). The role of plaice is gradually replaced by saithe and young haddock with increasing depths, and large haddock contributes significantly at the deepest trawling stations (h,e). Large cod and Norway lobster dominate in the eastern part along the Swedish coast (i), and the latter species is replaced by saithe at deeper waters (g). Young cod constitute a significant part of the catches in the eastern part of the survey area as well as in a smaller part north off Hirtshals (i,j).

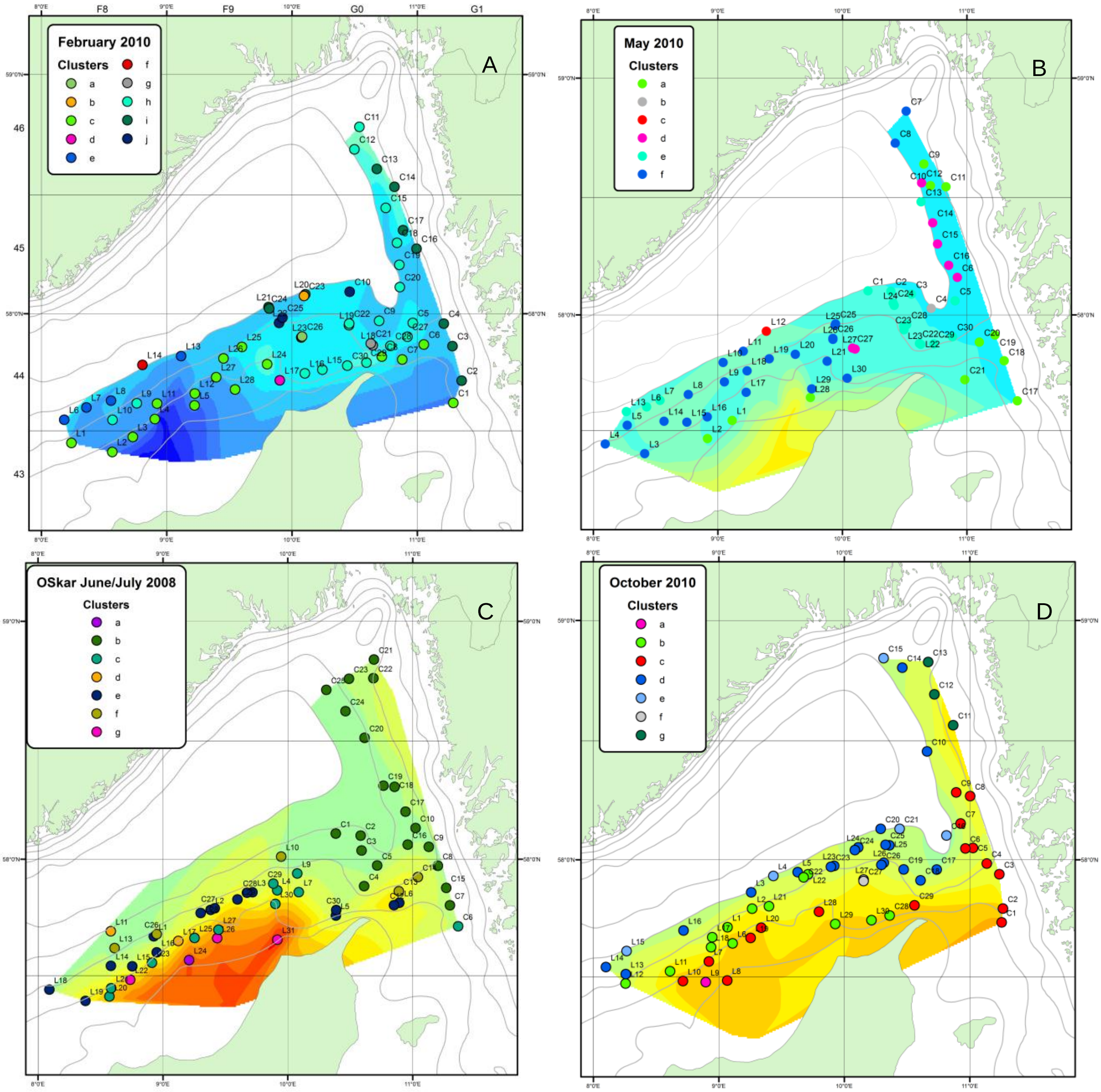


Figure 25. Maps illustrating the results of the cluster analysis. Showing the location of the clusters for each of the four Oskar surveys on top of the temperature maps based on temperature measurements from the respective surveys. A: 1st quarter survey (February 2010), B: 2nd quarter survey (May 2010), C: 3rd quarter survey (June/July 2008), D: 4th quarter survey (October 2010).

Quarter 2 (Fig. 25.B & Tab. 4)

Like in the first quarter of the year, plaice and large cod dominate the catch composition in shallow water (50-100 m) over the entire survey area (a). In the western and northern part plaice is partly replaced by saithe and young haddock in deeper water (in the western part in relatively shallow water as well) (f). At larger depths well above 100 m, young haddock are replaced by Norway lobster (e). Young cod constitute a significant part of the catches in the eastern part of the survey area as well as in a smaller part north off Hirtshals (d).

Table 4. Description of the 2nd quarter clusters, number of stations, average similarity within the group, species contribution and cumulative contribution.

2nd quarter Group	No of stations in group	Average similarity within the group	Species	Contribution %	Cum. %
A	11	72,17	Plaice>=27cm Plaice<27cm Cod>=30 cm	39,24 22,85 16,85	39,24 62,09 78,94
B	1	-	-	-	-
C	1	-	-	-	-
D	7	84,21	Cod>=30cm Saithe>=30cm Cod<30cm Plaice>=27cm	35,09 24,90 12,38 9,65	35,09 59,98 72,37 82,02
E	17	82,09	Saithe>=30cm Cod>=30cm Nephrops landed	38,03 27,60 10,38	38,03 65,63 76,00
F	23	79,97	Cod>=30cm Saithe>=30cm Plaice>=27cm Haddock<27cm	27,55 17,06 16,55 15,73	27,55 44,71 61,26 76,98

Quarter 3(Fig. 25.C & Tab.5)

Catches of plaice and Norway lobster were not recorded in this quarter of the year (2008). Catches in shallow water is dominated by cod (c,g), and in deeper water by haddock and saithe as well (d,e,f). Large cod and saithe totally dominate the composition in the eastern part of the area (b). Young cod contribute significantly in the western and central parts of the area (c,d,e,f).

Table 5. Description of the 3rd quarter clusters, number of stations, average similarity within the group, species contribution and cumulative contribution.

3rd quarter Group	No of stations in group	Average similarity within the group	Species	Contribution %	Cum. %
A	1	-	–	-	-
B	20	77,98	Cod>=30 cm Saithe>=30 cm	45,55 37,93	45,55 83,48
C	11	80,08	Cod>=30 cm Cod<30 cm	54,25 31,24	54,25 85,49
D	2	81,47	Cod>=30 cm Haddock>=27 cm Cod<30 cm	36,82 32,13 19,42	36,82 68,94 88,36
E	16	88,10	Cod>=30 cm Cod<30 cm Haddock>=27cm	30,39 24,21 21,74	30,39 54,59 76,33
F	5	87,18	Cod>=30 cm Saithe>=30 cm Haddock>=27cm Cod<30 cm	25,87 24,70 19,74 18,45	25,87 50,57 70,31 88,77
G	3	66,19	Cod>=30 cm	83,27	83,27

Quarter 4(Fig. 25.D & Tab.6)

Plaice, cod and haddock dominate the catches in shallow water with haddock replacing plaice at the deeper stations (b,c). Plaice and haddock are replaced by saithe at larger depths >100 m (d,e). Together with cod and haddock, Norway lobster contributes significantly to the catches from the north-eastern part of the survey area (g). The share of young cod is significant in all catches except those obtained from the deepest water (200 m).

Table 6. Description of the 4th quarter clusters, number of stations, average similarity within the group, species contribution and cumulative contribution.

4th quarter Group	No of stations in group	Average similarity within the group	Species	Contribution %	Cum. %
A	1	1 sample in group	-	-	-
B	13	80,64	Had>=27cm Cod>=30 Cod<30	31,17 27,22 17,69	31,17 58,40 76,08
C	16	69,08	Cod>30cm Plaice>27cm Cod<30cm	32,26 29,12 15,68	32,26 61,38 77,06
D	19	78,76	Saithe > 30cm Cod >30cm Cod<30cm	32,06 29,79 17,29	32,06 61,85 79,13
E	5	75,34	Saithe>30cm Cod>30cm	40,23 36,48	40,23 76,71
F	2	91,14	Cod<30cm Cod>30cm Neph.landed	31,73 25,99 21,59	31,73 57,72 79,31
G	3	85,14	Neph.landed Cod<30cm Haddock<27cm Cod>30cm	27,22 22,69 15,44 13,26	27,22 49,90 65,35 78,60

Distribution of commercial species in relation to depth and temperature

All trawler CPUE for haddock, cod, plaice split into smaller and larger than minimum landing size were plotted against depth and temperature for each quarter, the same was done for saithe but only larger than minimum landing size as only a few to small were caught (Fig. 26-29) in order to identify seasonal patterns in temperature and depth preferences.

Quarter 1

Young cod were predominantly caught at depths from 50 m to 170 m and temperatures from 5° C to 7° C. The catch rates of cod ≥ 30 cm followed those of young cod with the exception that they did not decrease at larger depths. Both groups of cod seemed to avoid temperatures below 4.5° C (Fig. 26). The caches by depth of young haddock followed those of cod ≥ 30 cm, while the distribution of haddock ≥ 27 cm was displaced to larger depths (Fig. 27). The catch pattern for saithe (Fig. 29) is mainly the same as for haddock ≥ 27 cm. Plaice do not seem to avoid low temperatures and the catch rate decrease with increasing depth for young plaice as well as for plaice ≥ 27 cm (Fig. 28).

Quarter 2

The catch rate of young cod decrease with increasing depth, while it is evenly distributed among depths for cod ≥ 30 cm (Fig. 26). The depth distribution of haddock (Fig. 27) resembles that of cod ≥ 30 cm, while the temperature distribution is skewed towards higher temperatures than cod because of the predominantly western distribution of the species. The catch rate of saithe increases with increasing depth (Fig. 29). The catch rate of plaice decrease with increasing depth, this is similar to what is observed in the first quarter of the year (Fig. 28).

Quarter 3

Young cod are primarily distributed between 25 m and 100 m and seem to prefer temperatures of 7–12° C. Cod ≥ 30 cm are evenly distributed among depths above 25 m and temperatures below 12° C (Fig. 26). The depth distribution of catch rates of haddock is similar to that of young cod (Fig. 27). Large catch rates of saithe are predominantly obtained at depths above 100 m and temperatures below 8° C (Fig. 29). Data on plaice are inadequate (Fig. 28).

Quarter 4

The depth distribution of young cod was similar to that in the previous quarter of the year, but with higher CPUE in deeper water, which probably reflects the higher temperatures at 100–200 m. Cod ≥ 30 cm were evenly distributed among depths above 25 m (Fig. 26). The catch rate patterns for haddock and saithe are similar to those of quarter 3 (Fig. 27 and 29). The catch rate of plaice decreases with increasing depth in the same way as in quarter 1 and 2 (Fig. 28).

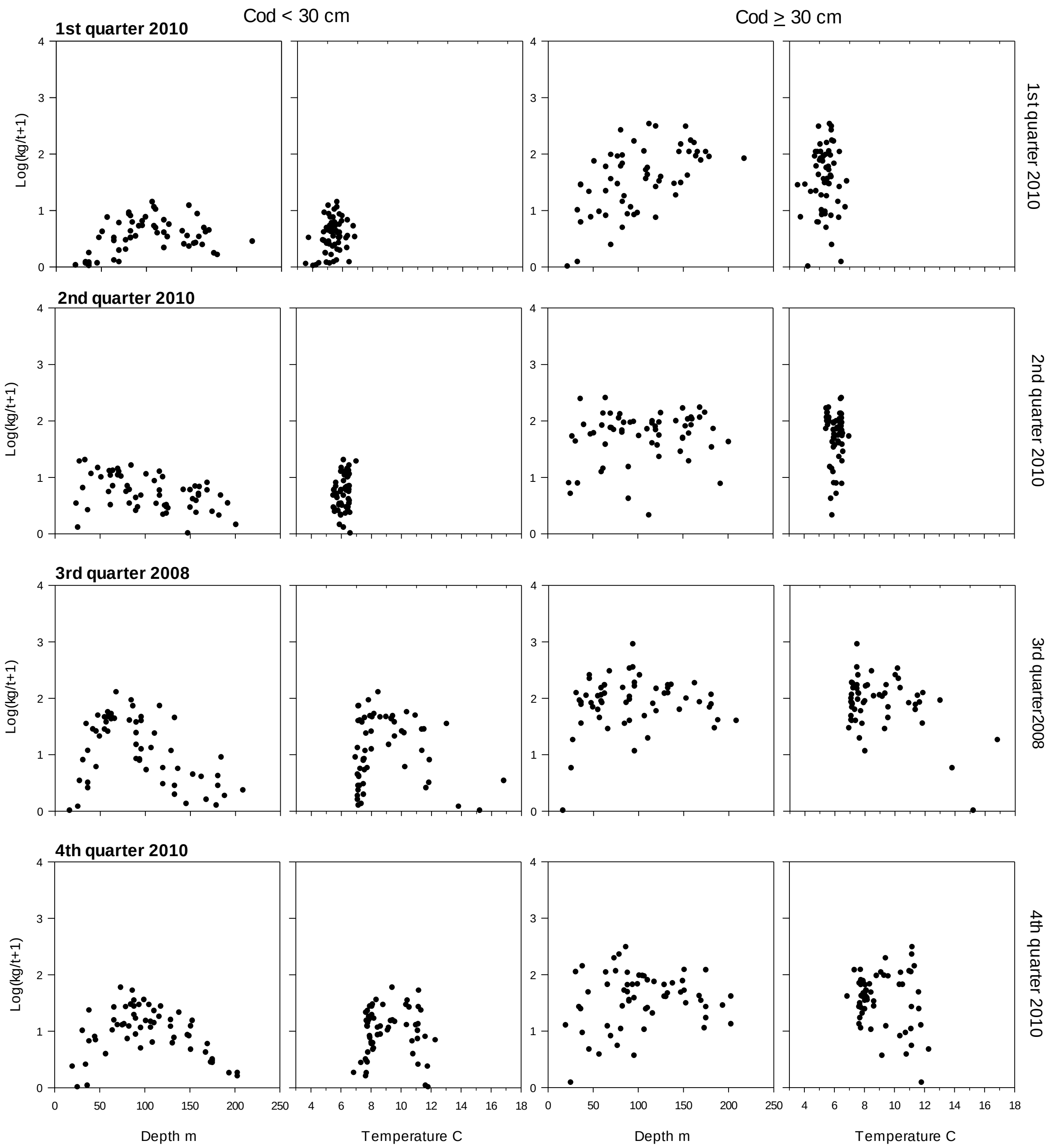


Figure 26. The CPUE (log(kg/h+1) of cod smaller and larger than minimum landing size plotted against depth an temperature respectively for each of the four surveys.

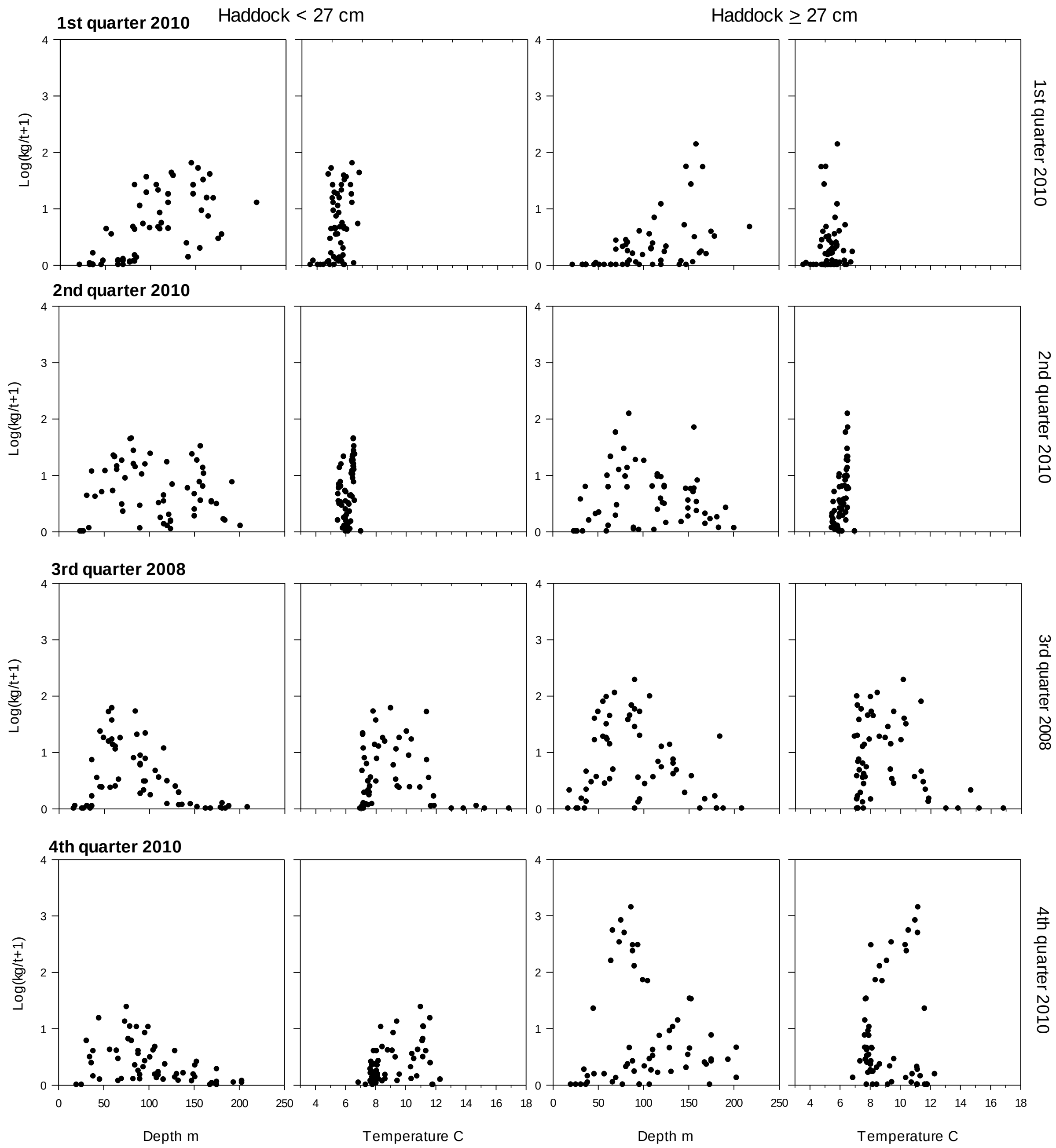


Figure 27. The CPUE (log(kg/h+1) of haddock smaller and larger than minimum landing size plotted against depth an temperature respectively for each of the four surveys.

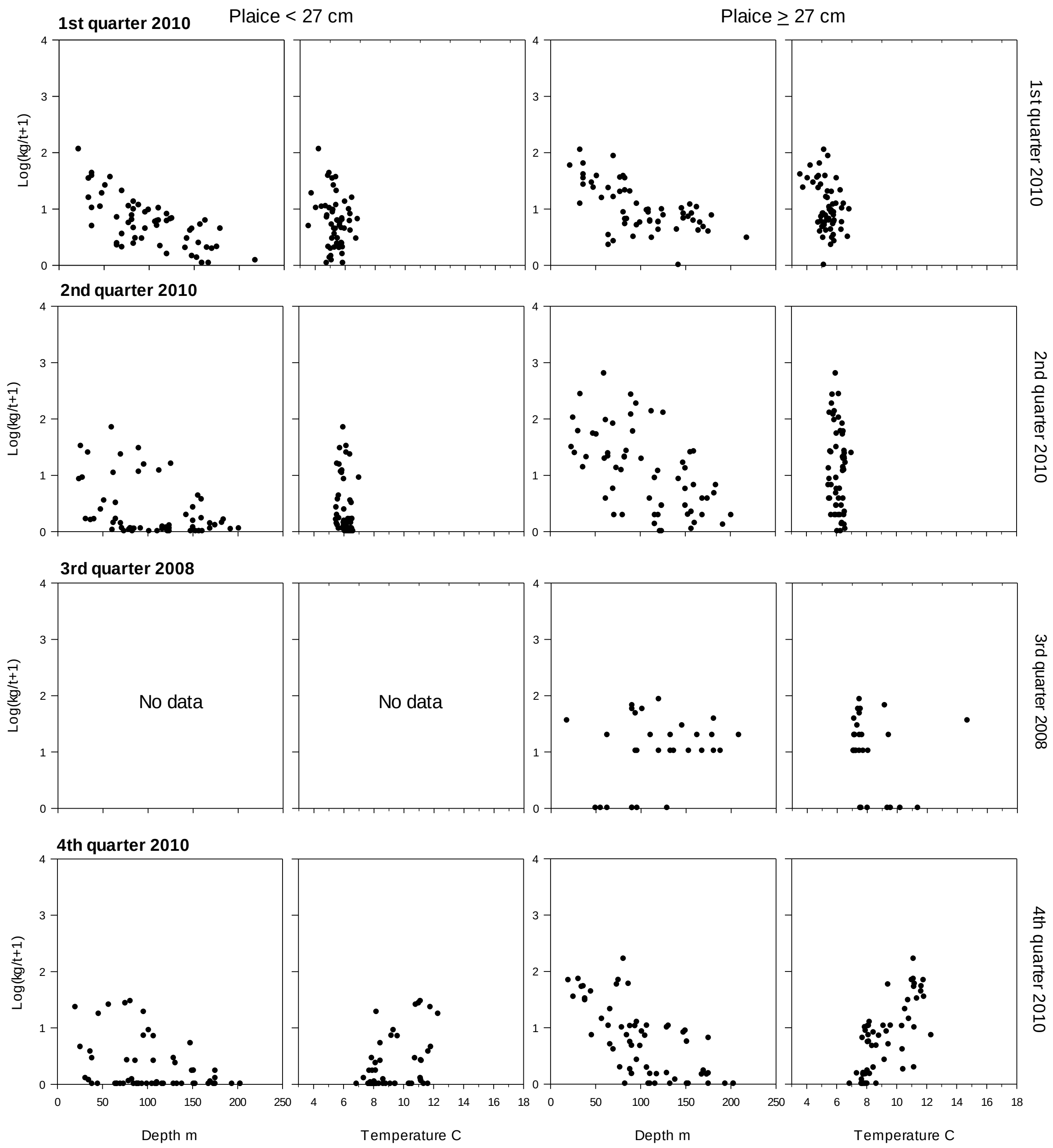


Figure 28. The CPUE (log(kg/h+1) of plaice smaller and larger than minimum landing size plotted against depth an temperature respectively for each of the four surveys, except for small plaice 3rd quarter where no data were collected.

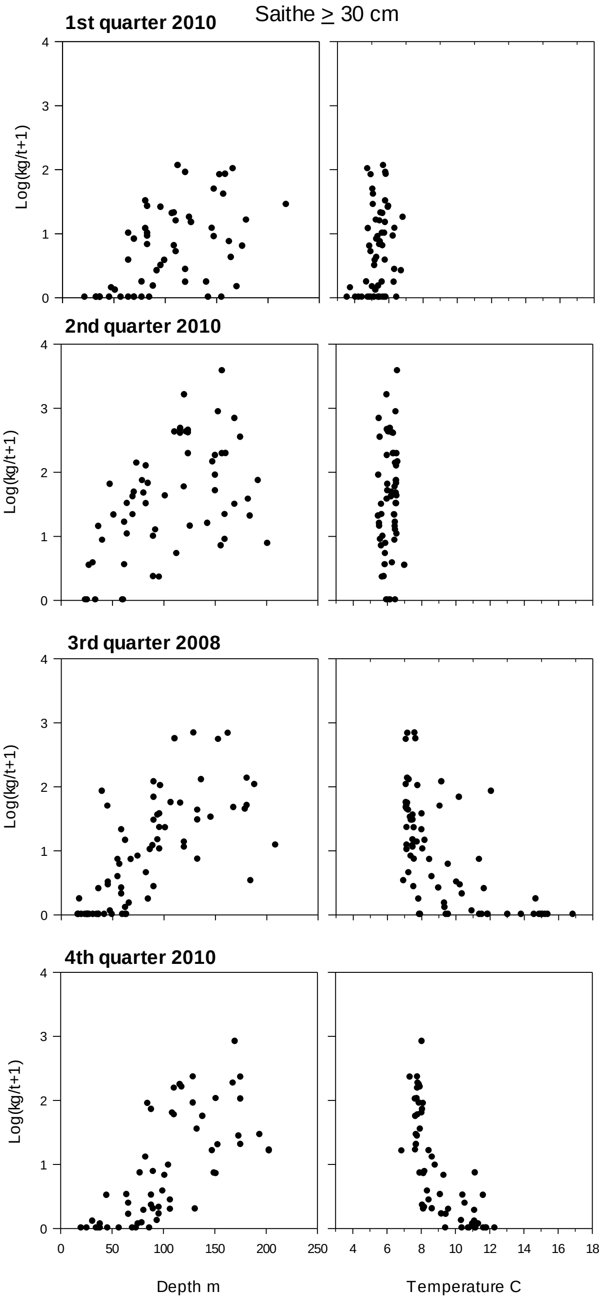


Figure 29. The CPUE (log(kg/h+1) of saithe plotted against depth an temperature respectively for each of the four surveys.

Cod below minimum landing size in all quarters

Cod below minimum landing size was predominantly found at depths from 25 to 125 m in all surveys but the occurrence outside the preferred depth range differed between the sampling dates (Fig. 30). This indicate the influence of seasonal effects and suggest that closing fishing areas across a fixed range of depth contours would not be appropriate in every case to protect small cod.

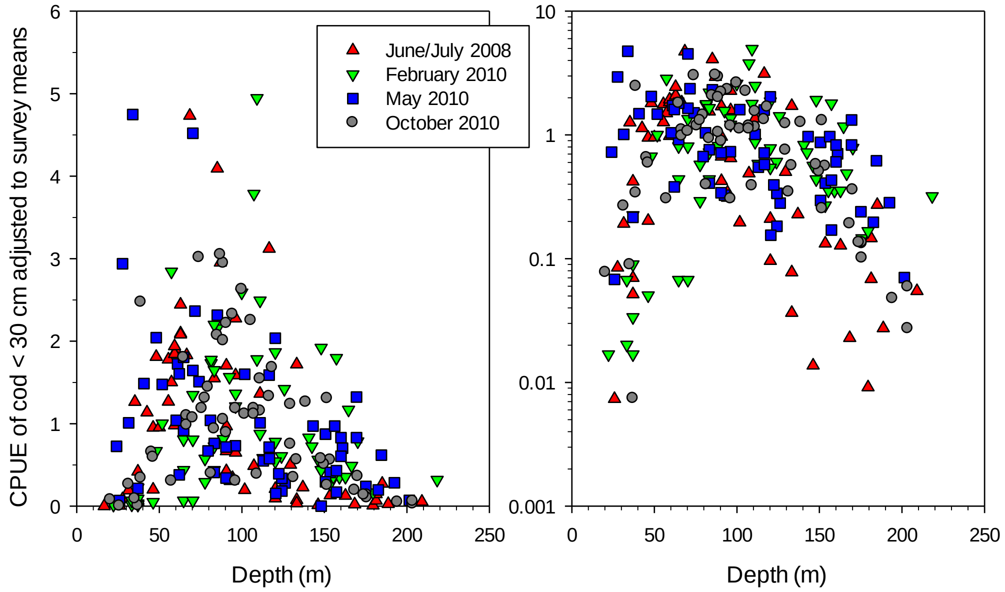


Figure 30. Depth distribution of small cod for all stations covered by the two trawlers during the four OSkar surveys based on catch rates adjusted to the respective survey means.

The distribution of catch rates of small cod showed no clear pattern in relation to bottom temperature except that small cod seem to avoid temperatures below 4 °C and above 13 °C (Fig. 31). Considerable within-survey variability was observed for all four sampling dates indicating that the distribution of catch rates of small cod at given time of time year is governed by other factors than temperature.

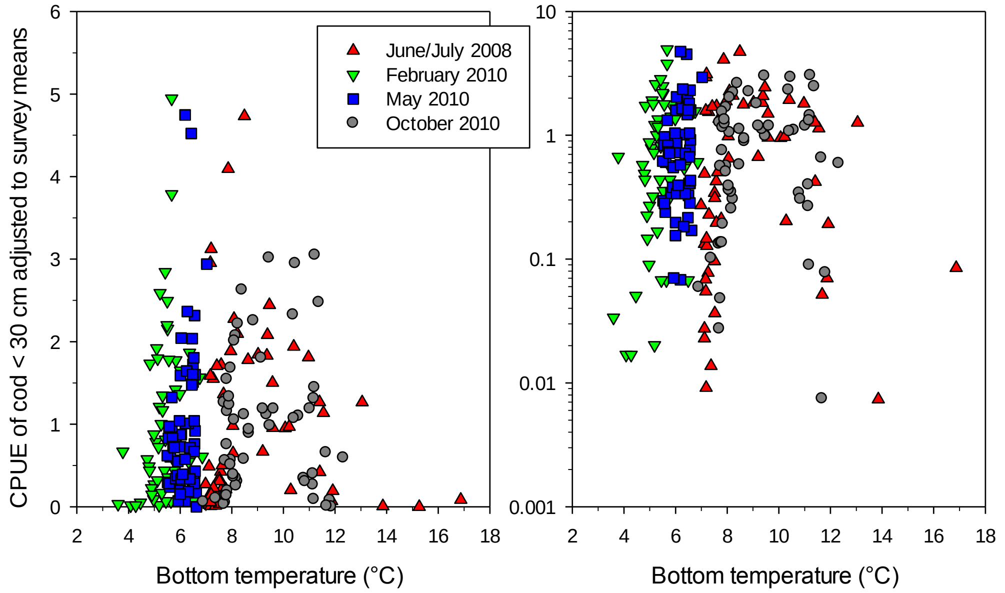


Figure 31. Distribution of small cod in relation to bottom temperature for all stations covered by the two trawlers during the four OSkar surveys based on catch rates adjusted to the respective survey means.

Effect of bottom current speed and turbidity on catch rates of cod

Gillnetter catch rates of cod adjusted to the respective survey did not show a clear relationship with bottom current speed or turbidity (Fig. 32), but almost no cod was caught at stations with bottom currents above 0.35 m/s.

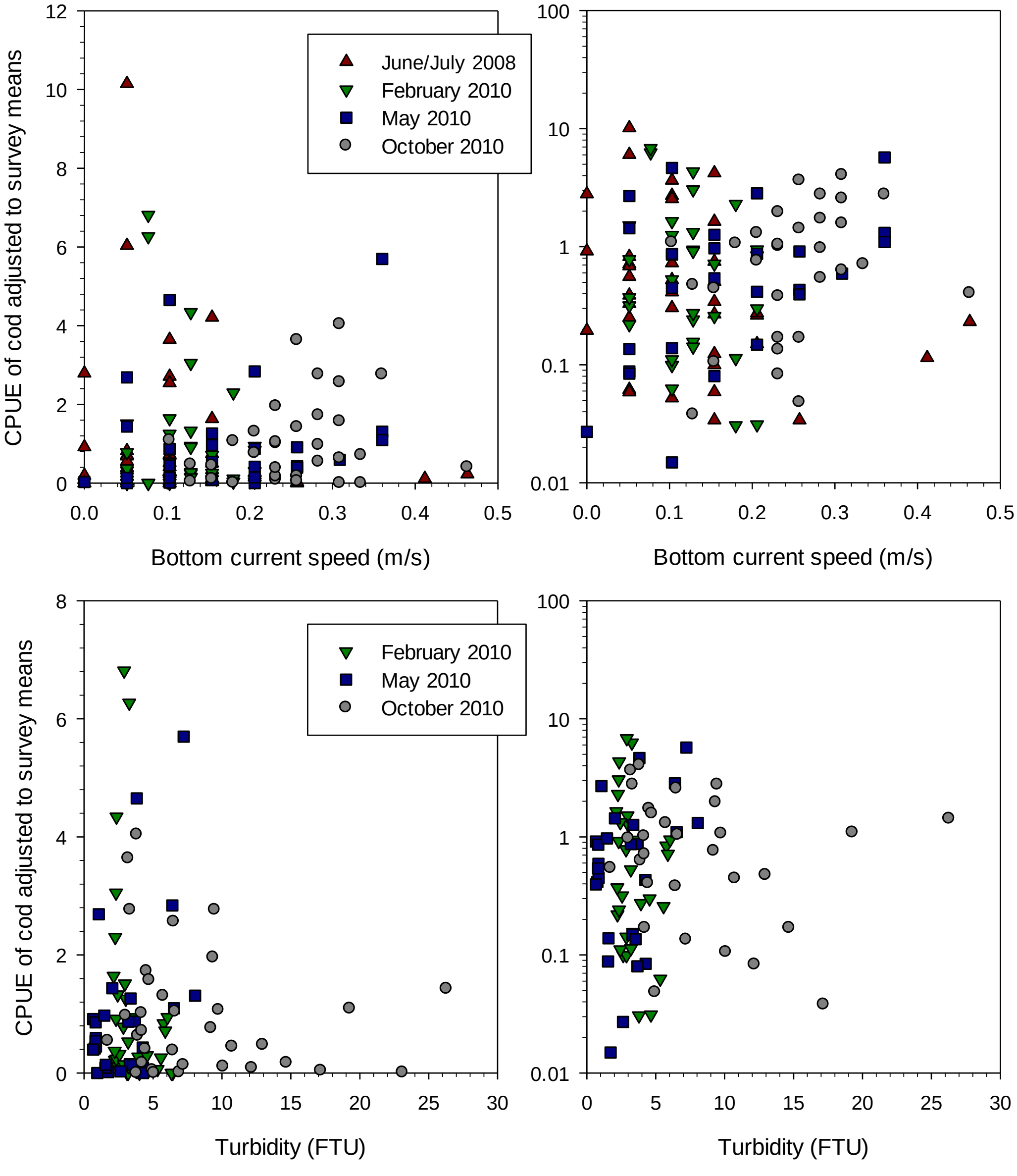


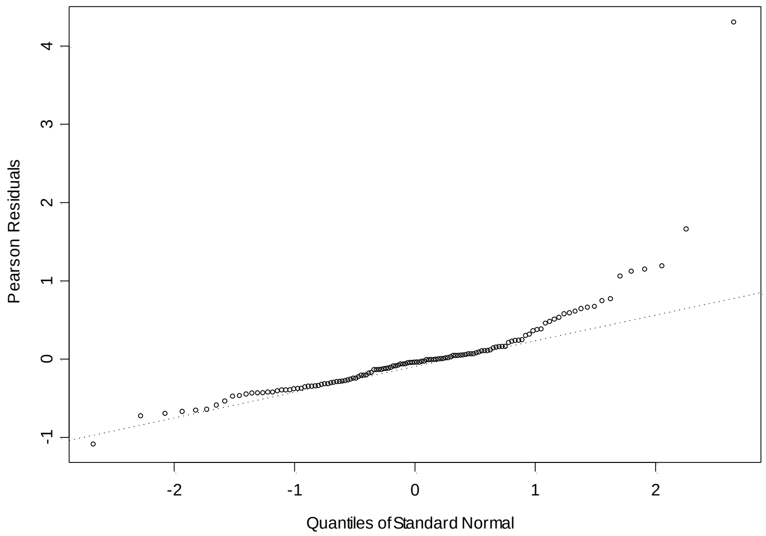
Figure 32. Gillnetter catch rates of cod adjusted to the respective survey means in relation to bottom current speed and turbidity.

GAM (General Additive Model) analysis was carried out for the southwestern Skagerrak in which bottom current speed and turbidity were considered as covariates in addition to survey, bottom type and depth:

$$CPUE \sim survey + bottom\ type + f_1(depth) + f_2(bottom\ current\ speed) + f_3\,(turbidity)$$

where survey and bottom type were treated as factors, and f_1, f_2 and f_3 are smoothing functions. Smoothing splines and a Gaussian error with the identity link were used.

Neither depth nor turbidity was significant for the data set from the three surveys carried out in 2010. This allowed the inclusion of the survey in June/July 2008, for which no data on turbidity had been available, in the final analysis. Here, bottom current speed was not significant (P = 0.1034, Fig. 33) indicating that the observed catch rates were unbiased and are not affected by the observed range of bottom current speed and turbidity.



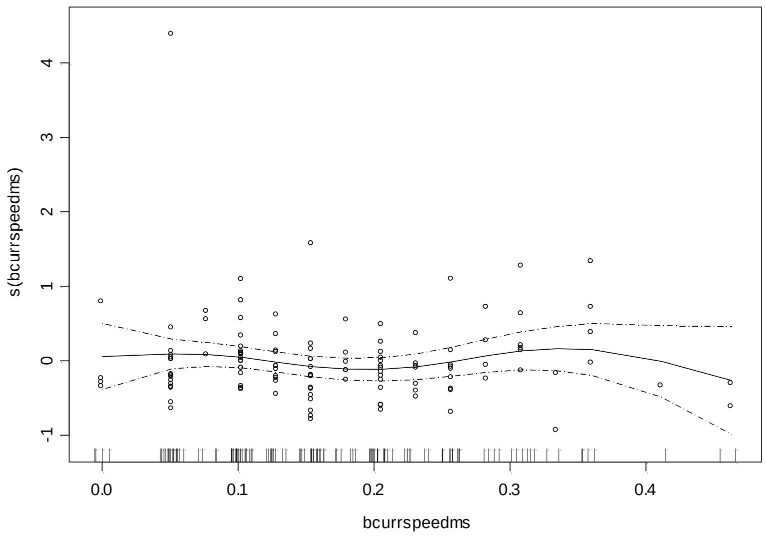


Figure 33. Model diagnostics (Normal quantile plot) and spline smoothing for the effect of bottom current speed on gillnetter catch rates of cod during the four Oskar surveys.

Unwanted by-catch of commercial species and real time closures

By-catch of commercial species below minimum landing size in relation to total catch suitable for landing

The geographical distribution of the proportion (in weight) of the trawler catches of undersized individuals of commercial species in relation to the total catch of commercial species above minimum landing size are presented in Fig. 34 for each of the OSkar surveys.

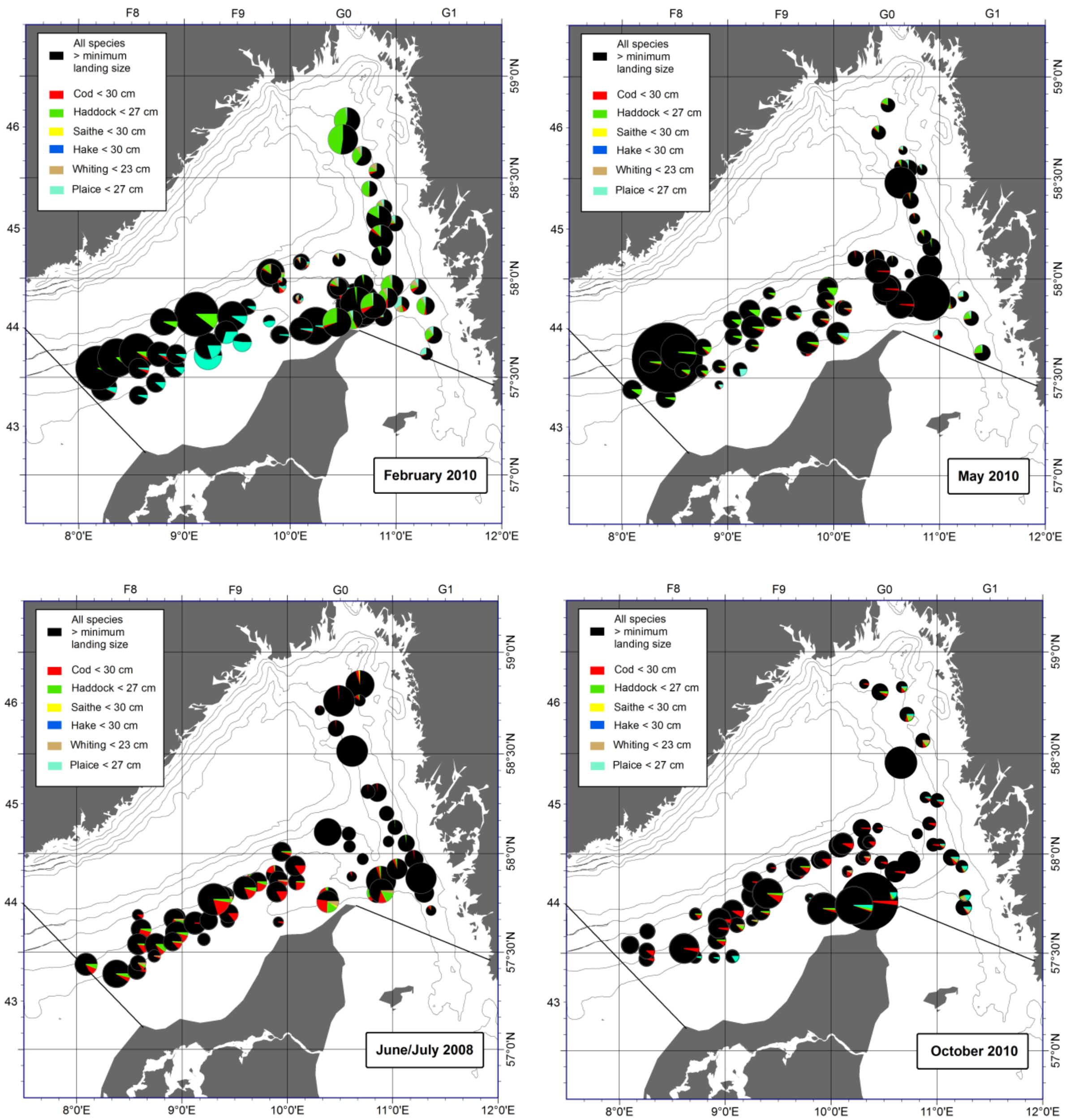


Figure 34. Geographical distribution of trawler catches of undersized commercial fish species in relation to total catch for the four OSkar surveys (plaice below minimum landing size were not recorded in June/July 2008).

In June/July 2008, the weight of small cod in relation to the total catch of commercial species amounted up to 25 % in the western Skagerrak but was considerably lower in the other parts of the area and during the other surveys in general. In February 2010, small haddock and small plaice made up a high proportion of the catches in the northeastern and western Skagerrak, respectively. In May 2010 and in October 2010, by-catch levels of undersized fish were below 10 % for all of the different commercial species. Average catch of small cod relative to the total catch of all commercial species above minimum landing size ranged from 0.04 kg/kg in May 2010 to in 0.10 kg/kg in June/July 2008.

For all sampling dates combined, no significant positive correlations between the catch rates (in numbers per hour fishing) of undersized cod and haddock and the catch rates of all commercial species for landing, saithe and Norway lobster above minimum landing size were found (Fig. 35a-b). In contrast, a significant positive correlation between the catch rates of small cod or small plaice and cod above minimum landings size was found.

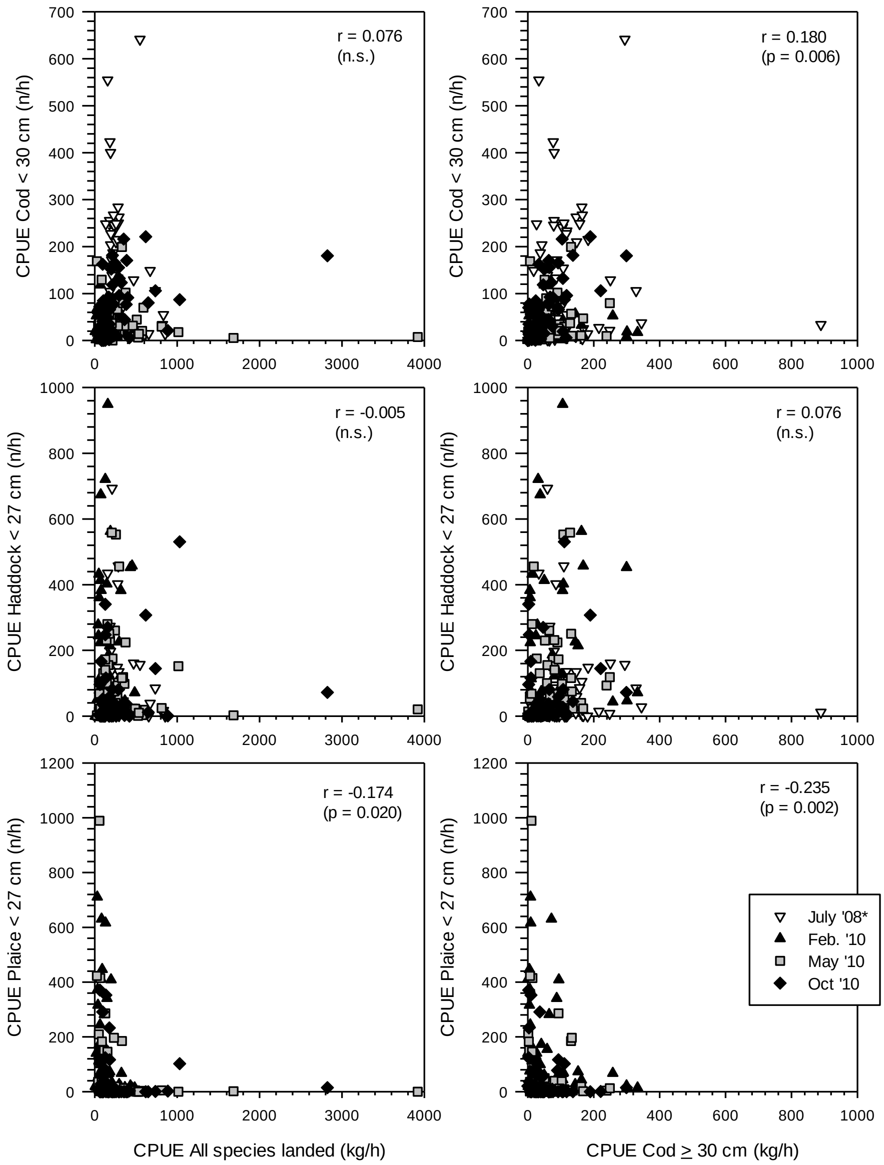


Figure 35a. Comparison of catch of small cod, haddock and plaice with catch rates of all species landed and catch rates of cod above minimum for the four OSkar surveys (*: small plaice were not recorded in June/July 2008).

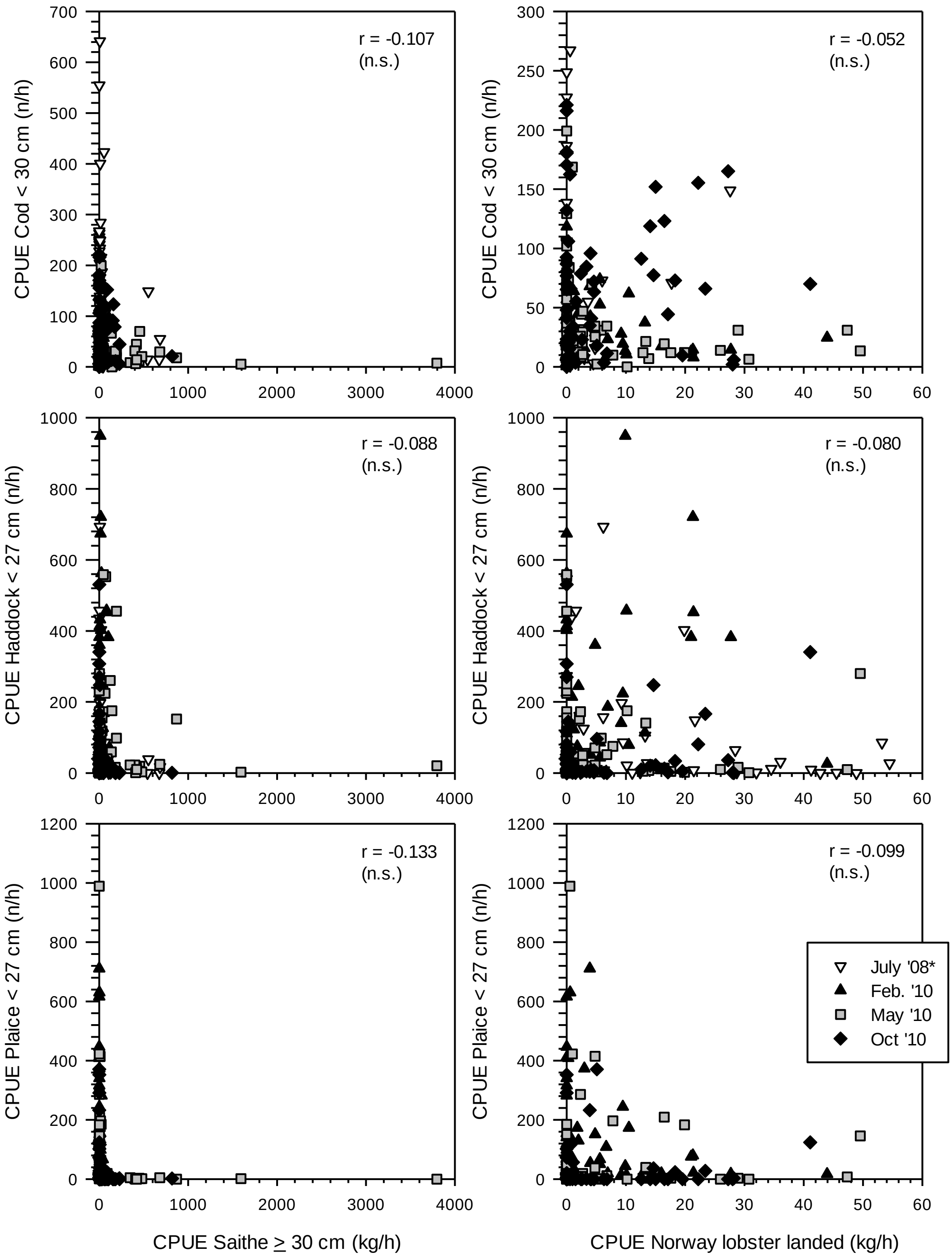


Figure 35b. Comparison of catch of small cod, haddock and plaice with catch rates of saithe above minimum landings size and Norway lobster retained for landing for the four OSkar surveys (*: small plaice were not recorded in June/July 2008).

The trawl fishery in the Skagerrak has the possibility to optimize the catch for human consumption without necessarily increasing the discard of undersized commercially important species when targeting mixed species, saithe or Norway lobster by choosing the appropriate fishing areas and times of the year, but this appears to be more difficult when targeting cod. Hence, the fishery may consider establishing an internal real time warning systems about the actual distribution of small cod and other gadoids below minimum landing size in order to avoid closures of fishing areas.

The gillnetter caught very few cod below minimum landing size. Small cod (< 30 cm) was only present in the gillnetter catches at 13 out of the 125 stations taken during all surveys together. Total discard of undersized commercial fish in the gillnetter catches were almost negligible (Fig. 36) and even the highest values at single stations did not exceed 0.5 % of the total catch for human consumption in weight. The average length frequencies for each survey can be seen in figure 37.

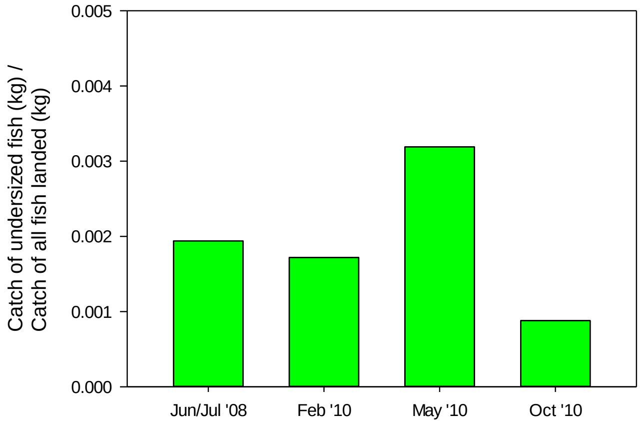


Figure 36. Average total catch of commercial species below minimum landing in relation to the total catch of commercial species above minimum landing size in the gillnetter catches from the four OSkar surveys.

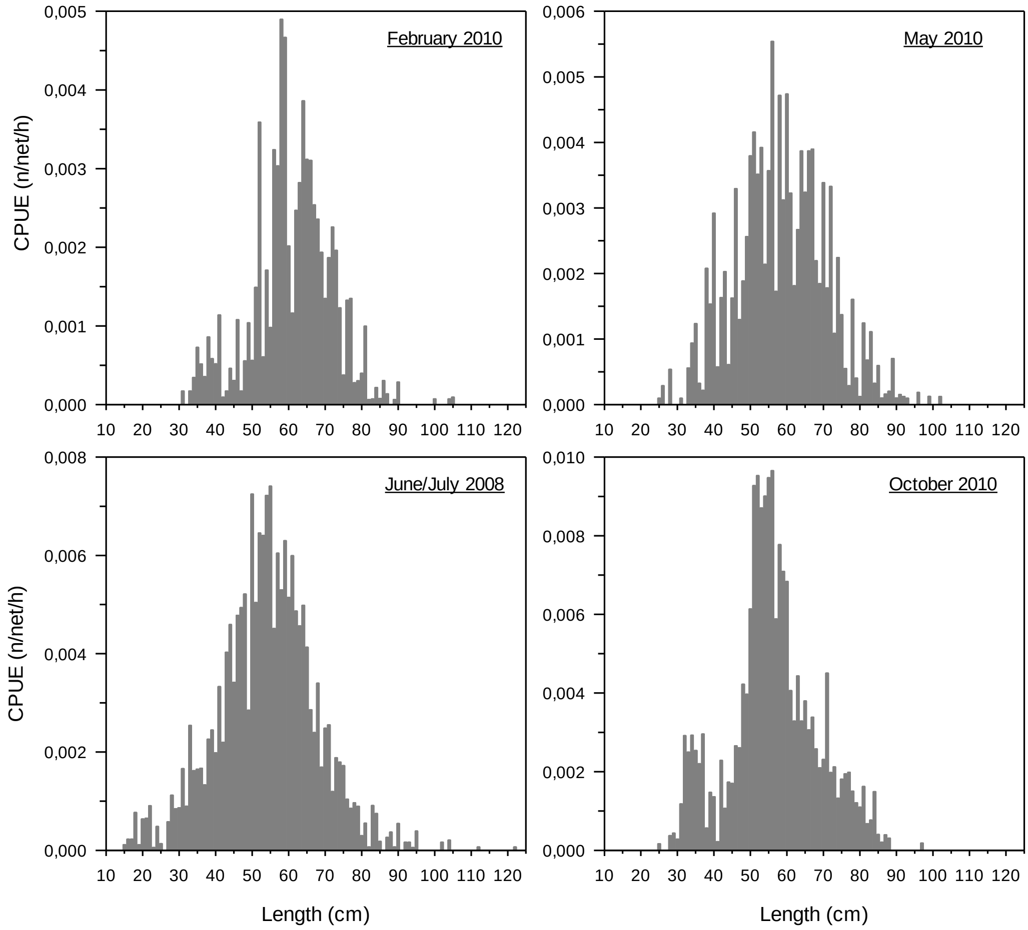


Figure 37. Cod length frequencies of gillnet catches for all four Oskar survey. Illustrated as numbers of cod/net/hour as a survey average.

Catch rates of undersized gadoids and real time closures

Real time closures – regulations and controls

In order to protect gadoid young fish of the species cod, haddock, saithe and whiting, Norway and the EU in 2009 made an agreement for Skagerrak and North Sea involving real time closures. The agreement was first described in regulation (EF) nr. 753/2009 and basically set a limit for the percentage by mass of young fish in the catches. If the percentage of a sample exceeds the limits, an area of 50 square nautical miles is closed for demersal fisheries for 21 days. It was implemented by 1st of September 2009. In Skagerrak, there is a difference between the legal minimum landing size and the EU definition of young fish (Table 7). Making a catch only including gadoids above minimum landing size a catch that potentially can close down an area.

Table 7. Definition of young fish and minimum landing size in Skagerrak for gadoids considered in the EU regulations; (EF) 753/2009, (EU) 724/2010 and (EU) 783/2011.

Minimum landing size Skagerrak:	**Definition of young fish according to EU regulations:**
Cod: 30 cm	Cod < 35 cm
Saithe: 30 cm	Saithe < 35 cm
Haddock: 27 cm	Haddock < 30 cm
Whiting: 23 cm	Whiting < 27 cm

This regulation has been updated a few times since then. However, the latest change was implemented by 13th of August 2011 ((EU) 783/2011) decreasing the lower limit for how large the gadoid catch should be to be considered from 300 kg to 200 kg, and decreasing the maximum percentage of young fish in the catch from 15 % to 10 % (Table 8).

Table 8. Short list of the main rules and major changes regarding real time closures in Skagerrak and the North Sea.

The new and old rules for real time closures (differences are highlighted):	
<u>Old rules: (EF) 753/2009 & (EU) 724/2010</u> - To consider a sample - minimum catch of **<u>300 kg</u>** of cod, haddock, whiting and saithe. - The young fish of cod, haddock, saithe and whiting can maximum contribute **15%** to the total catch of these species. - If cod contribute more than 75% to the total catch, the contribution from young fish (cod, haddock, saithe and whiting) can maximum be **10%**	<u>New rule: (EU) Nr. 783/2011</u> - To consider a sample - minimum catch of **<u>200 kg</u>** of cod, haddock, whiting and saithe. - The young fish of cod, haddock, saithe and whiting can maximum contribute **10%** to the total catch of these species. - If cod contribute more than 75% to the total sample, the contribution from young fish (cod, haddock, saithe and whiting) can maximum be **7.5%**

The number of effectuated closures from the legislation was implemented by 1st of September 2009 and until the 12th of September 2011, is according to the sample list from The Danish Directorate of Fisheries, limited to five closures (four in Skagerrak). However three of these five closures were effectuated within one month after the new regulation (EU 783/2011) in only five samples (> 200 kg), two of the three closures were in Skagerrak. According to The Danish Directorate of Fisheries, they sampled 29 times in 2011 (until 21/8-11), and the catch was large enough to constitute a valid sample in only 13 of these occasions. Within this period, only two closures took place (Figure 38).

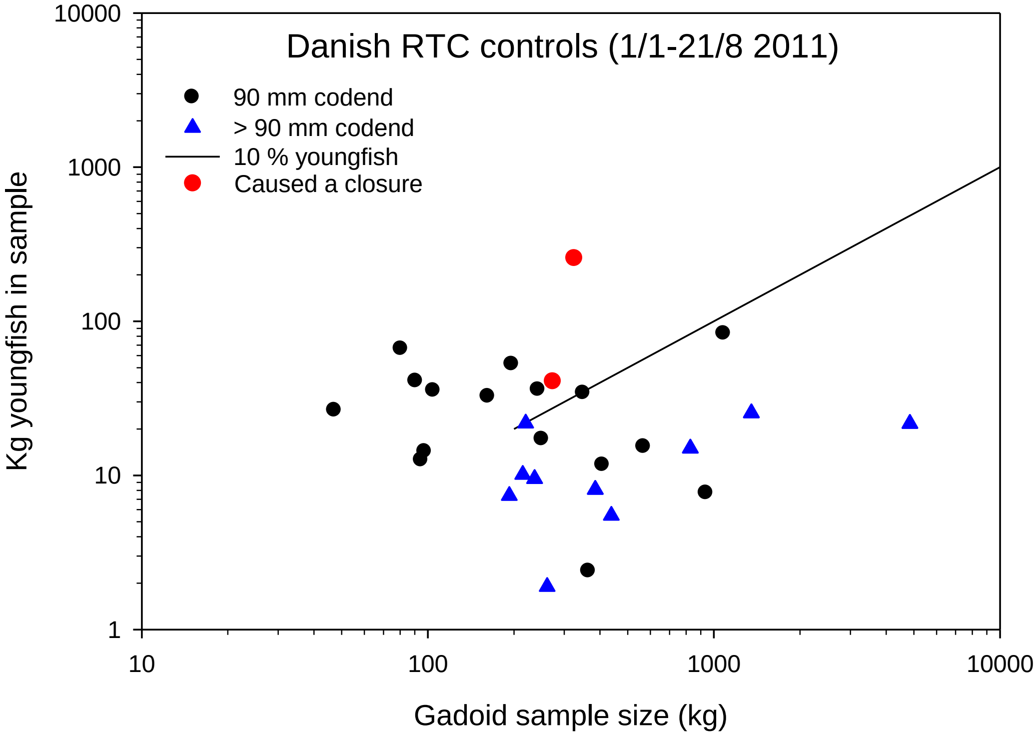


Figure 38. Total gadoid catches (kg) plotted against the gadoid youngfish catch (kg). Data from the Danish RTC controls in the period 1/1-11 to 21/8-11.

OSkar data and real time closures

To identify potentially problematic areas we tested whether the Oskar stations would have caused a real time closure either by the old rule or by both the old and the new rule because a closure by the new rule also would cause a closure by the old rule (Table 8.). In this analysis we found that 50 of the 235 Oskar trawl stations would have caused closure according to the old rule only, and 89 stations would have caused a closure by the new rule. The geographical and seasonal distributions of these stations are illustrated in Figure 39-42A. As a background colour in the figures we interpolated the percentage of young gadoids (weight) found for each station with a gadoid catch > 10 kg. It is however very important to emphasise that these results do not reflect the Skagerrak fishery in general as gear type, mesh size, target species and fishermen behaviour affect the catch.

Method

The aim of this project is to obtain knowledge to avoid unjustified closures of fishing grounds and due to the surprisingly high number of Oskar stations that potentially could have caused a realtime closure we wanted to see what the composition of the gadoid catch would have looked like if we had used a 120 mm codend instead of 90 mm. We therefore recalculated the catch at each station using the method described in details below and afterwards calculating the new weight using the length/weight relationships described in Coull et al. (1989). Then we made the same exercise as with the ordinary Oskar survey data, tested whether the calculated catch could cause a real time closure and by interpolating the % young fish a coloured background map was created (Fig. 39-42A). To get an idea of which species and sizes that contributes to the coloring the length frequencies of Oskar data and the 120 mm calculation are plotted in Figure 39-42C.

Calculation of the numbers and size distributions of gadoids in a trawl with 120 mm codend

The size-specific retention in a 120 mm codend was calculated for each of the gadoid species from the retention in a 90 mm cod end by use of estimated parameters to equation (1). The probability of retention of a gadoid of length *l* (cm) in the codend was calculated as

$$r(l) = \frac{\exp\left((l-l_{50})\ln(9)s_R^{-1}\right)}{1+\exp\left((l-l_{50})\ln(9)s_R^{-1}\right)} \qquad (1)$$

where the values in Table 9 of the 50% retention length l_{50} and selection range s_R (= $l_{75} - l_{25}$) parameters were obtained from experiments on retention of each of the gadoid species in a 90 mm codend (Frandsen *et al*. 2009) and a 120 mm codend (Krag *et al*. 2011), respectively. Subsequently, the number n_{120} of fish by length group (1 cm width) retained in a trawl with 120 mm codend was calculated as

$$n_{120} = n_{90}r(l)_{120}[r(l)_{90}]^{-1} \qquad (2)$$

where n_{90} is the observed number in the OSKAR survey trawl with 90 mm codend, and $r(l)_{120}$ and $r(l)_{90}$ are the probabilities of retention of fish of length *l* in the two respective codends.

Table 9. Selection parameter estimates obtained from experiments with standard codend of two different mesh sizes.

	90 mm codend*		120 mm codend†	
Species	l_{50}	s_R	l_{50}	s_R
Cod	23.02	6.97	37.3	14.8
Haddock	22.91	7.41	29.6	8.5
Whiting	26.10	7.39	37.8	7.6
Saithe (pollock)	-	-	39.9	5.2

*Nominal mesh size of 90 mm (MO 92.5 mm); 5 mm PE double twine; 92 open meshes in circumference (Frandsen *et al*., 2009).
†Nominal mesh size of 120 mm (MO 127 mm); 5 mm PE double twine; 100 open meshes in circumference (Krag *et al*., 2011).

Results

After applying the 120 mm selection to the Oscar data the number of stations affected by the real time closure rules. We found that 9 instead of 50 of the 235 Oskar trawl stations would have been closed according to the old rule only and 20 instead of 89 stations would have caused a closure by the new rule (Fig. 39-42A&B). As seen on the length frequencies 120 mm have a significant selection on the young gadoids.

In 1st quarter the main contributor to the red colouring is haddock (Fig. 39) but after the 120 mm calculation the around 4000 individuals at 20 cm is reduces to around 1000 individuals. This resulted in a reduction of the 5 red stations and 6 yellow stations, to only one yellow station.

In the 2nd quarter the whole area almost turn green after the 120 mm transformation (Fig. 40) due to a big loss of small cod and haddock and almost a full retention of the saithe.

3rd quarter turns very green after the 120 mm selection treatment, but still has two red stations and a few yellow this is mainly due to generally small catches of larger gadoids (Fig. 41).

In the 4th quarter the area northwest of “grenen” remains in the reddish coloring mainly due to high frequencies of cod between 30 and 35 cm and haddock between 27 and 30 cm (Fig. 42). But the number of red stations has been significantly reduced from 20 to 7 stations.

Overall the use of 120 mm seems like a good way to reduce the risk of a real time closure. But it’s not 100% safe and the losses of valuable individuals are not considered.

A small guide to a fast interpretation of the maps (Fig. 39-42A&B)

- ▲ Green triangle in green areas: Less than 10% small gadoids in the total catch of gadoids.
- ▲Green triangles on orange or red colours: Small catches < 200 kg in two hours, but more than 15% young gadoids in the area. Increased fishing time could potentially be a problem.
- ● Yellow dots in yellow, orange or red areas: Catches between 200 and 300 kg in two hours. More than 10% young gadoids in the catch.
- ● Red dots in orange or red areas: Catches above 300 kg in two hours and more than 15% young gadoids in the area.

Again it is very important to emphasise that these results do not reflect the Skagerrak fishery in general as gear type, mesh size, target species and fishermen behaviour affect the catch.

This is data from a survey designed to catch gadoids in all sizes and should be seen as a tool to get an understanding of the potential catch composition.

Figure 39-42. The four maps combine the consequence of a control visit during the Oskar trawl surveys regarding real time closures and the percentage of young fish of the species cod, whiting, haddock and saithe caught during the four Oskar surveys in February 2010, May 2010, June/July 2008, and October 2010 including all surveys also very small catches. Both the consequences of the new (13/8-11) and the old rules are considered in the maps.
▲stations not within the risk of causing a realtime closure,
● stations causing a realtime closure only by the new rules,
● stations causing realtime closures by both new and old rules.

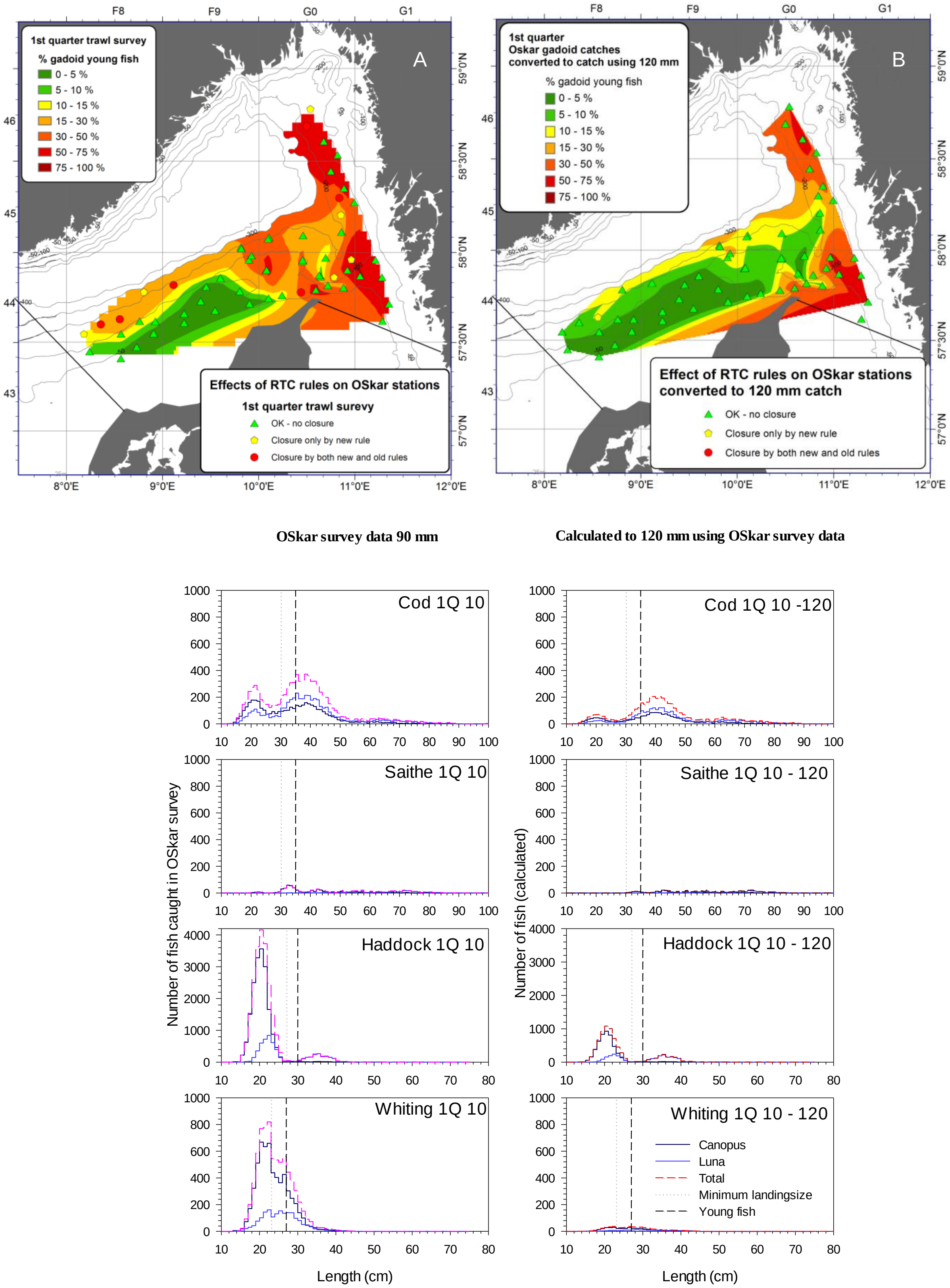


Figure 39. 1st quarter OSkar survey 2010. A: actual data, B: theoretical 120 mm catch, C: length frequencies of the four gadoid species to the left Oskar data using 90 mm, right column theoretical 120 mm frequencies.

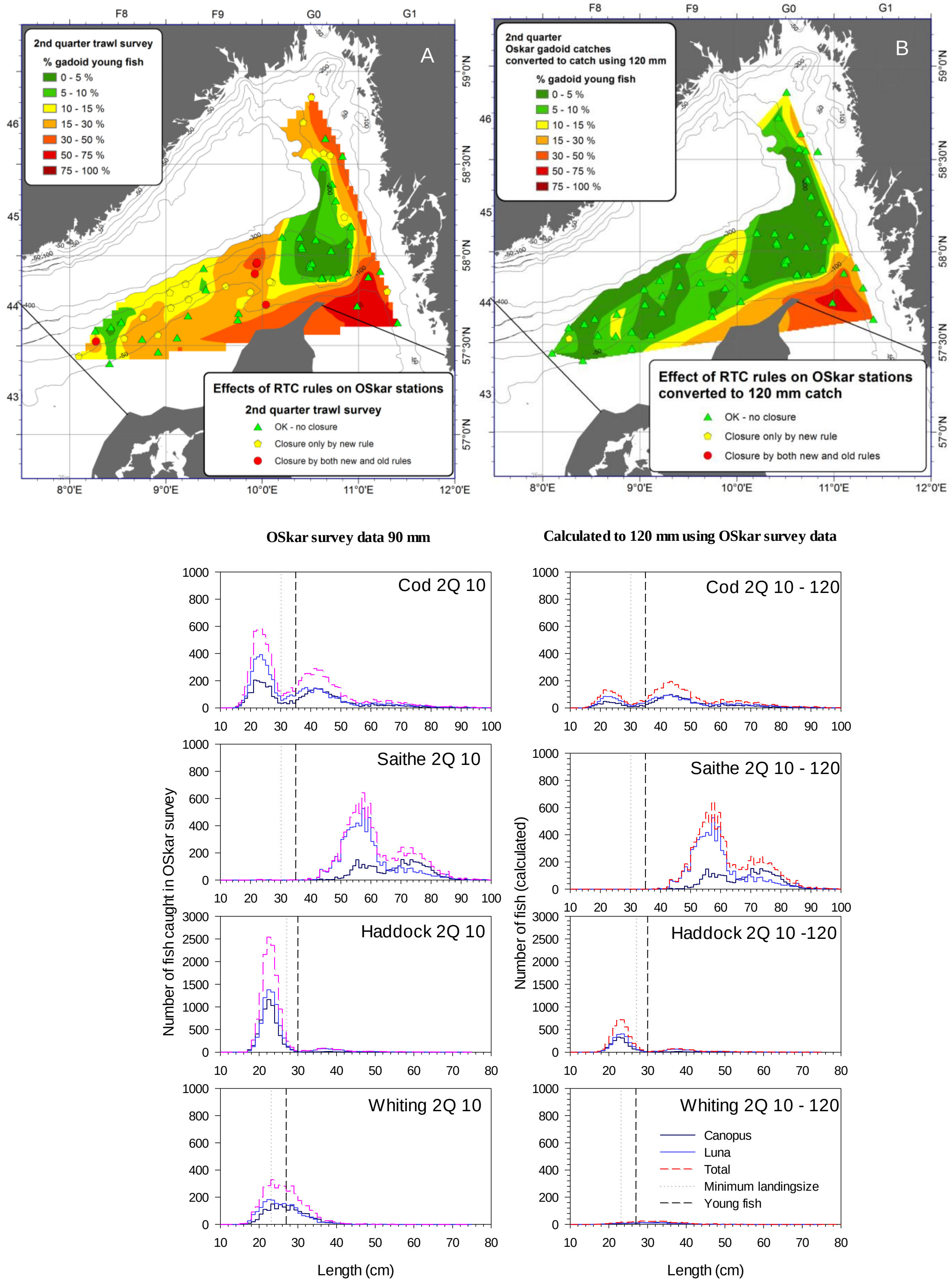


Figure 40. 2nd quarter OSkar survey 2010. A: actual data, B: theoretical 120 mm catch, C): length frequencies of the four gadoid species to the left Oskar data using 90 mm, right column theoretical 120 mm frequencies.

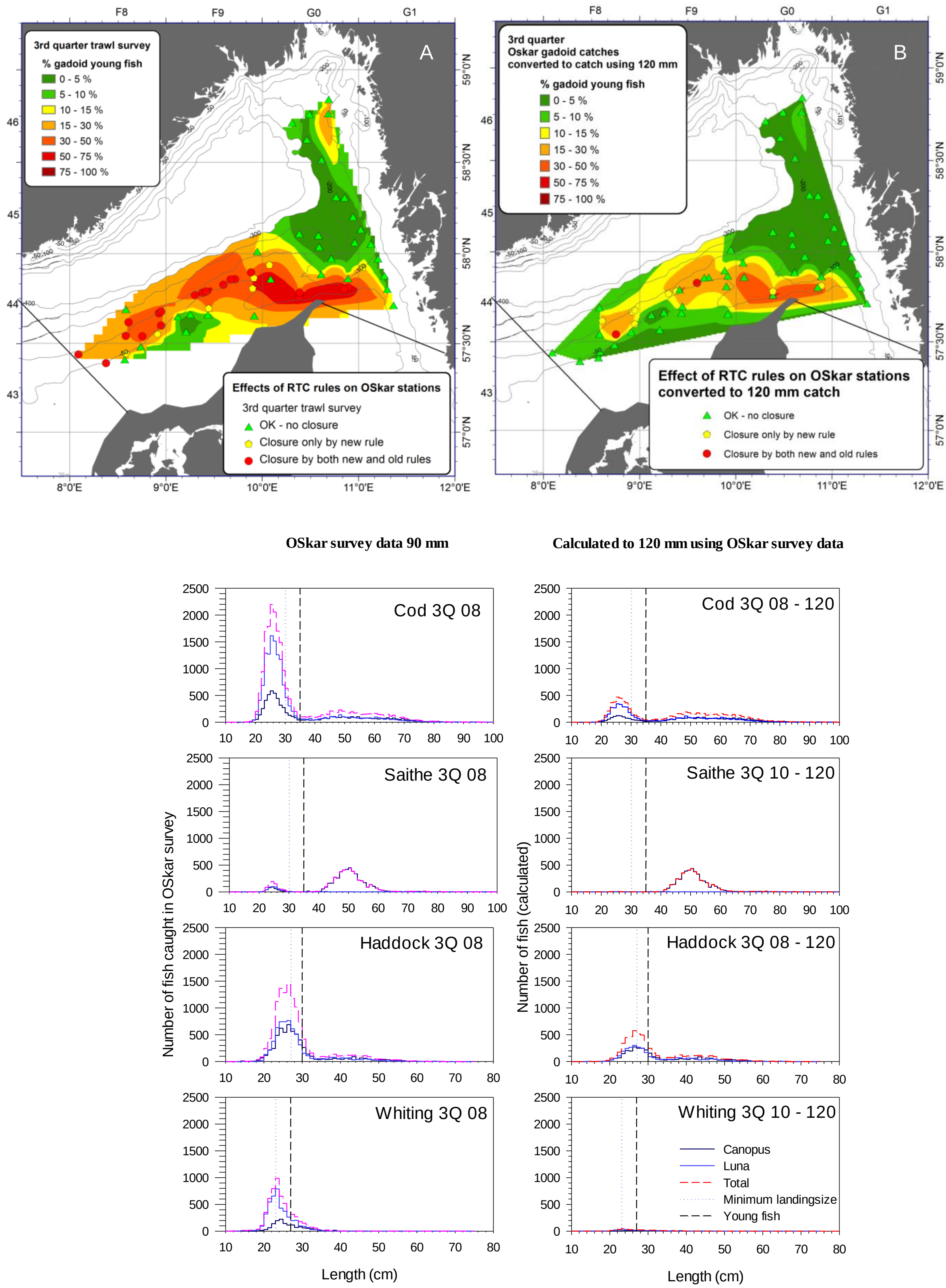


Figure 41. 3rd quarter OSkar survey 2008. A: actual data, B: theoretical 120 mm catch, C: length frequencies of the four gadoid species to the left Oskar data using 90 mm, right column theoretical 120 mm frequencies.

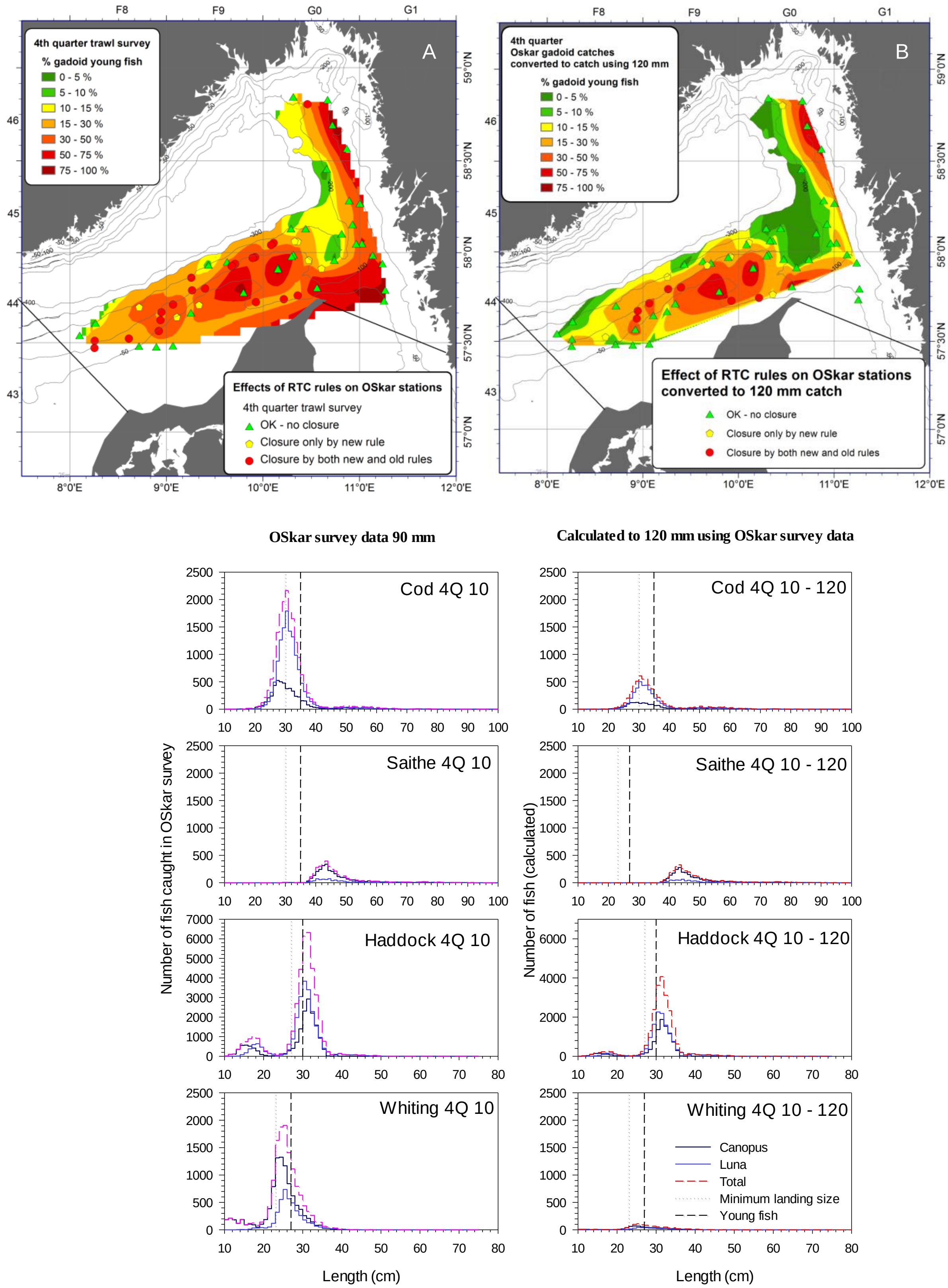


Figure 42. 4th quarter OSkar survey 2010. A: actual data, B: theoretical 120 mm catch, C: Length frequencies of the four gadoid species to the left Oskar data using 90 mm, right column theoretical 120 mm frequencies.

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(EF) Nr. 753/2009

(EU) Nr. 724/2010

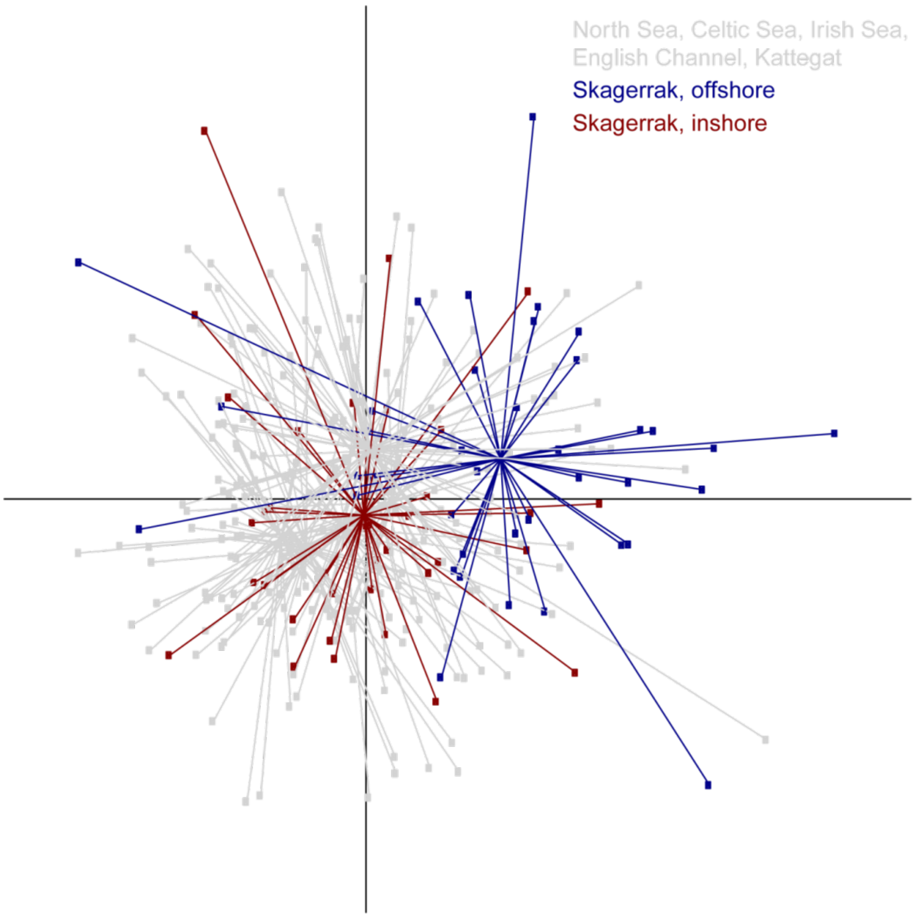
(EU) Nr. 783/2011

The Danish Directorate of Fisheries (2011): Realtidslukninger - Real Time Closures - Prøveresultater - NaturErhvervstyrelsen.

Work package E1

Genetic analysis of Atlantic cod

by Jakob Hemmer Hansen



Genetic analyses of Atlantic cod from Skagerrak

Fisheries management has traditionally been area based rather than population based. This practice could result in a mismatch between managed and biological units (Reiss *et al*. 2009), potentially leading to the mismanagement of important natural resources, for instance due to a failure to recognize separate biological units which may respond differently to fishing pressure within a management area. Thus, knowledge about the geographical scale of population structuring could be useful for fisheries management because it would allow targeted harvesting of specific population components. Genetic methods may therefore also be an integrated tool in future real-time and catch-quota management schemes by allowing the traceability of individual fish back to the geographical origin of catch and by enabling an estimation of the proportion of individual catches originating from different population components. Furthermore, genetic data could be integrated with modeling approaches estimating current and future population strength in relation to known and projected geographical distribution of fishing pressure.

Genetic techniques have been widely used for delineating units of reproductively isolated individuals (i.e. populations), but until now their application in marine fisheries management has been limited. Most studies conducted so far have found that marine fishes are characterized by limited levels of genetic population divergence, thus requiring high statistical power for population discrimination and potentially limiting the integration of genetics with fisheries management. However, communication gaps between fisheries and evolutionary biologists have also been highlighted as partially responsible for the lack of integration (Waples *et al*. 2008). Since genetic methodology has traditionally targeted genetic (evolutionary) independence rather than demographic (ecological) independence (which is often more relevant to fisheries management (Waples and Gaggiotti 2006; Waples *et al*. 2008)), it has been difficult to integrate the two research disciplines. Recent technological developments have, however, revolutionized fish population genetics and have stimulated studies of population structure and local adaptation on both large and local spatial scales (Nielsen at al. 2009a). In particular, the application of genetic markers linked to genes potentially under selection has made it possible to address processes on both evolutionary and ecological scales, thus bridging the gap of time scales traditionally challenging the communication between evolutionary and fisheries biologists.

Atlantic cod is one of the most intensively studied species in marine fish population genetics. Several studies have identified populations on both large and local geographical scales. For instance, small but statistically significant genetic differences have been identified among Norwegian coastal cod samples collected within a few kilometers (Knutsen *et al*. 2003; 2011). Studies of variation in life-history characters (Olsen *et al*. 2008) suggest that these genetic differences do in fact reflect true biological differences. In one recent study, Poulsen *et al*. (2011) examined a number of genetic markers linked to genes of potential physiological importance and found genetic differences between offshore and inshore locations for one specific gene. This study is among the first to suggest adaptation on local geographical scales using genetic markers in the species (see also e.g. Nielsen *et al*. 2009b). However, the amount of data from the North Sea/Skagerrak area was relatively limited as relatively few genes and geographical localities were analyzed. Thus the spatial scale of local adaptations is so far poorly known, particularly in the Skagerrak area which has received relatively limited attention.

A pilot study

In order to confirm and extend previous work, we carried out a pilot study, increasing the number of genes to approximately 1000 from the same samples as previously suggested to be locally adapted in the eastern North Sea (Poulsen *et al*. 2011). In addition, we included genetic information from reference samples collected in the Skagerrak and North Sea (Figure 1).

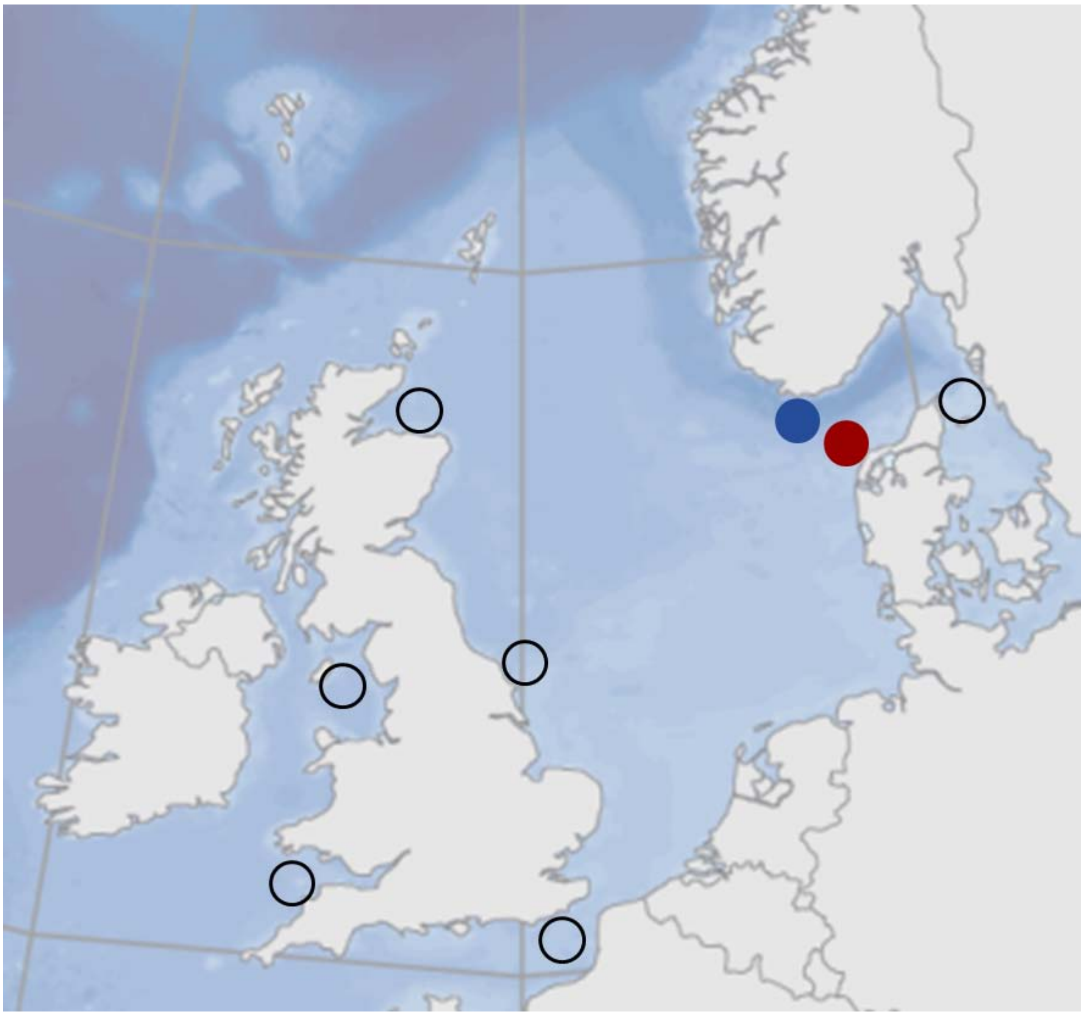


Figure 1. Sampling locations of Atlantic cod analyzed in the pilot study. Red is inshore location, blue offshore location. Black circles represent reference samples from adjacent areas.

Population structure

Population structure was examined through a principal component analysis (PCA) of all genes collectively. Here, it was evident that the offshore sample was different from all other samples and that all other samples clustered together without clear geographical patterns (Figure 2). It was also evident, however, that each of the samples were characterized by a high degree of individual variation.

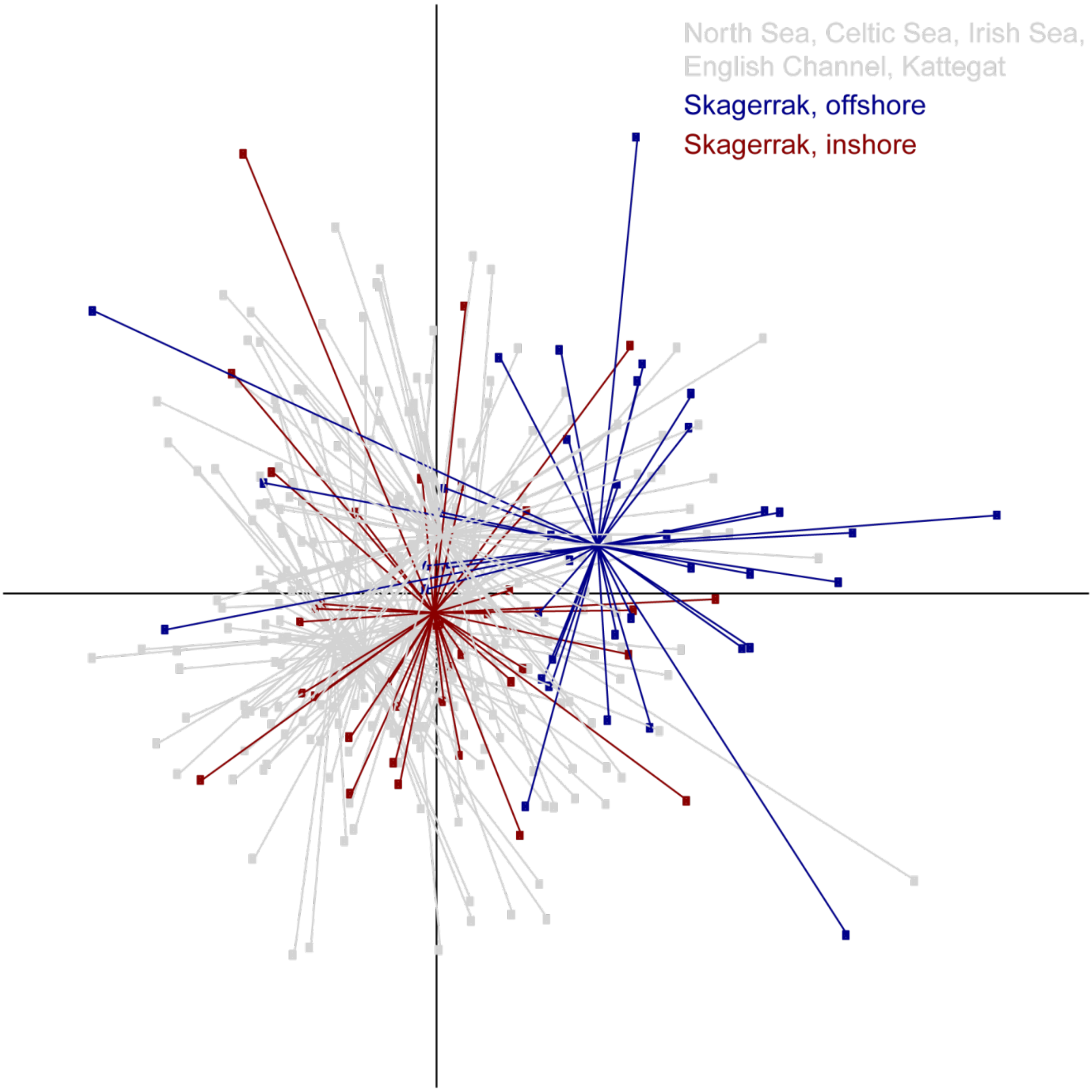


Figure 2. Principal component analysis (PCA) of all genes analyzed collectively. Squares represent individuals which are connected to the location centroid through straight lines.

Signals of selection

The offshore and inshore localities from the eastern North Sea were analyzed in more detail by applying a simulation based test to assess if specific genes showed higher (or lower) levels of population divergence than the "average" gene which is not assumed to be subject to selection (i.e. involved in adaptation to local environments). Results from the test showed that the majority of genes did not show higher levels of population (i.e. offshore vs. inshore) divergence than expected. However, a number of genes displayed very high levels of divergence (Figure 3), suggesting that fish from the two areas need different variants of the genes in order to survive and reproduce in their local environment.

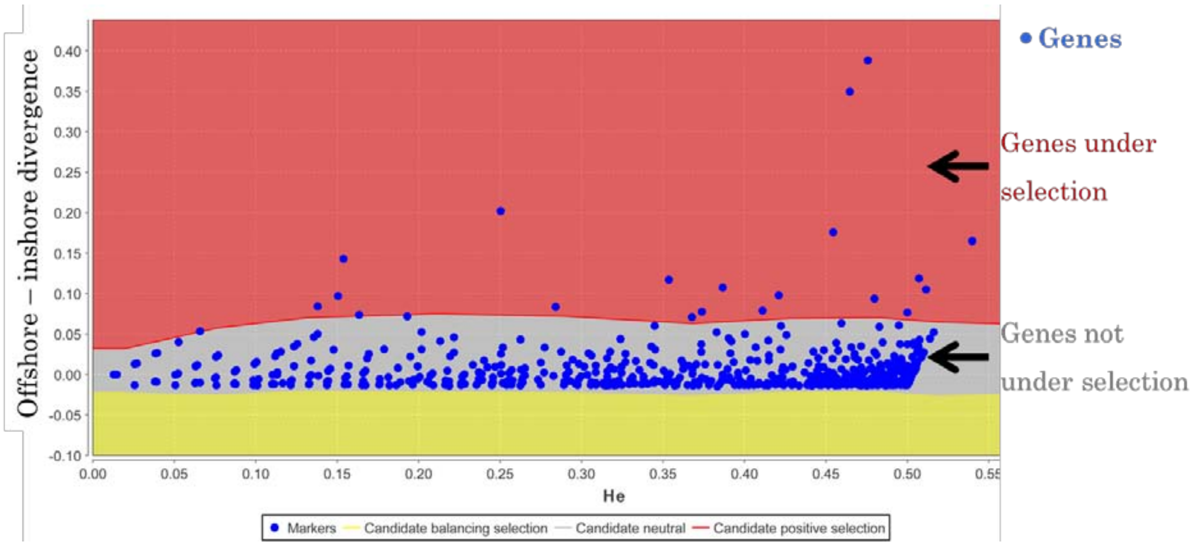


Figure 3. Simulation based test for extreme levels of population divergence between offshore and inshore localities. The y axis represents genetic divergence while the x axis represents genetic variation. Each blue dot represents one gene. Genes in the red area show higher than expected levels of population divergence (95% significance level), suggesting that the genes are involved in local adaptation.

What is required to identify the population structure?

Our preliminary results clearly support recent studies suggesting that population structure in the North Sea is more complex than previously believed. In particular, the finding that several genes appear to be involved in adaptation to offshore vs. inshore localities is interesting, lending support to recent work proposing that populations may be adapted on very fine geographical scales (Olsen *et al*. 2008; Poulsen *et al*. 2011).

Future work should integrate genetic data with ecological and oceanographic data (e.g. obtained from data storage tags) in order to link genetic patterns with the ecology and physiology of individuals in the field. Such knowledge would greatly improve our understanding of the underlying genetic patterns, a critical step if data should be implemented in fisheries management. Importantly, these activities would benefit significantly from a close cooperation with local fishermen who possess unique local knowledge about the distribution of individuals as well as the physiological characteristics of individuals from different areas. Fishermen would also be extremely valuable when designing and implementing an efficient sampling scheme.

In conclusion, there is a great potential for major cross-disciplinary research projects linking genetics, ecology and physiology in order to improve our understanding of population structure of Atlantic cod in the North Sea/Skagerrak area. Detailed knowledge about the population structure in the Skagerrak would require a dedicated study with detailed geographical sampling in the area to map the population structure as a baseline for future work. Importantly, both spatial and temporal scales should be considered in order to evaluate spatio-temporal dynamics in the system. Thus, both short-term (i.e. seasonal) and long-term (i.e. decadal, available from otolith collections) temporally replicated samples should also be included. Subsequently, these samples should be analyzed with high-throughput genetic techniques, allowing several hundred to thousands of genes to be analyzed collectively. No previous study has specifically targeted the Skagerrak area, and it would be very important to link population structure in the Skagerrak with the North Sea, Norwegian coasts and the transition zone between the North Sea and the Baltic Sea, which have all been studied intensively (e.g. Knutsen *et al*. 2003; Nielsen *et al*. 2003; Knutsen at al. 2004; Nielsen *et al*. 2009b; Poulsen *et al*. 2011).

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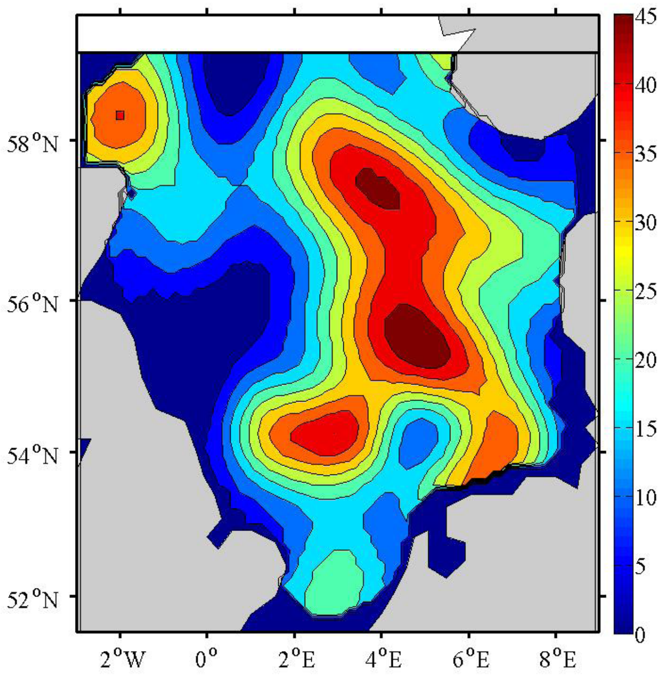
Work package E2

Spawning and larval dispersion of Atlantic cod

by Patrizio Mariani



Modelling spawning and larval dispersion processes

Introduction

A Lagrangian Individual Based Model (IBM) for eggs and larvae of cod *Gadus morhua* was developed and tested in the North Sea. The IBM was coupled to available state-of-the-art oceanographic physical model and we simulated spawning and larvae dispersion processes in the North Sea and the Skagerrak for the years: 2004, 2005, 2006 and 2007.

Description of the model

The biological processes included in the IBM were described at different early life stages of the cod:

- EGG STAGE: eggs were released in the spawning area on a given day and they were considered to be passive moving. Hatching time was parameterized using a temperature- and age-dependent growth function (Geffen et al., 2006). After hatching, the absorption of yolk sac was assumed to be completed after one week (Yin & Blaxter, 1987). When the absorption of the yolk sac was terminated numerical particles were assumed to enter the “larval stage” and they employed active diel vertical migration as described below.

- LARVAL STAGE: At first feeding, the length L_0 of the larvae was assumed to be 3 mm (Daewel et al., 2011). Subsequently, they grew according to the age dependent growth rate function :

$$G(age) = c_1 * age + c_2 \tag{1}$$

  where c_1 and c_2 are constants. Size affected the swimming capability of the larvae. Larvae were assumed to employ a diel vertical migration, migrating from 40 m during the day to 10 m depth at dusk and night (Munk et al., pers. comm.). The migration speed towards those preferential depths was assumed proportional to 1 body length per second. Constant values for Eq. 1 were derived from (Nielsen & Munk, 2004) (Figure 1).

- SIMULATED PERIOD: the model was run for 5 months between end of January and end of June. This period allowed simulation of the main spawning period of Atlantic cod in the North Sea. We simulated particle dispersion from January to June 2004-2007.

- SPAWNING: A probability function for cod spawning in the North Sea was reconstructed from interpolated egg distribution of a series of intensive ichthyoplankton surveys in February 2004 and 2009 (Hoffle et al., in prep.). This probability function (Figure 2) was then used to release numerical particles in the model. Birth or hatch date are important parameters to determinate the fate of fish larvae (Wright et al., 2009) and we developed a maturation sub-model in order to parameterize them properly.

Egg release and adult maturation model

It is well known that oocyte diameter of Atlantic cod is governed by temperature-dependent rates of vitellogenesis, which in turn directly regulate the timing of spawning (Kjesbu, 1994, Genner et al., 2010). Thermal regulation of gonad maturation has been proposed as the mechanism driving earlier larval appearance of marine fish in the North Sea (Lange & Greve, 1997). Moreover it has been suggested that Atlantic cod have the tendency towards later timing with increasing latitude and that distribution of cod eggs in different areas might prove existence of spatial variability in spawning time (Wright et al., 2003). We modelled this effect calculating the cumulative temperature distribution between 10 and 40 m in the North Sea and selecting the day at which this value was above a given threshold. A similar method was used to analyze recruitment and distribution of flatfish in the North Sea (Lange & Greve 1997). We selected a cumulative period starting from January 2004, 2005, 2006, 2007 and a threshold T=340° C, which resulted in spawning dates in agreement with those usually assumed.

Data analyses

The concentration of larvae (C) in a given area was calculated from the final distribution of the larvae and by the sum of particles in the Eulerian numerical box of the model. Concentrations were also scaled with the number of particles released in the given area to obtain an index for particle aggregation:

$$\Omega = C(C_0 + 1)^{-1} \tag{2}$$

where C_0 is the initial particle concentration (particles released). $\Omega \rightarrow 0$ when larvae were transported out of an area, $\Omega > 1$ when larvae were aggregated in an area.

Results

The day of spawning (day of particle release) was not constant but spatially and temporally varying (Figure 3). In 2004-2006 the simulated egg releases were similar with a peak in February and a spatial variability in cod spawning from south to north and west to east) (Figure 3a-c). In 2007 however the spawning season appeared to be more spatially uniform and later in the year (Figure 3d). At the end of May and June in 2004-2007 cod larvae appeared to be distributed over the entire North Sea and often also in adjacent areas such as the Skagerrak (Figure 4). Larger cod larvae are more abundant in the western part of the domain in all years but in 2007 where a more uniform size distribution was present in May and June. Relative concentrations (Figure 5) were always higher in the eastern part of the North Sea and in the Skagerrak, but a large year to year variability is simulated in the latitudinal displacement of the maximum appearing respectively more centrally and northerly (2005-2006) or centrally and southerly (2004 and 2007). In contrast to this large variability in C, maps of Ω (Figure 6) showed a more consistent pattern among different years. Two areas of large active aggregation of larvae (as defined in Eq. 2) were present in the western part of the North Sea close to the British coast and in the Skagerrak just north of Jutland. From January to June the number of particles present in the Skagerrak (> 57 °N and > 8.6 °E) showed large fluctuations but with similar intensity in 2004 and 2005 (Figure 7a, b) while higher and relatively more stable inflow was present in 2006 (Figure 8a) and in particular in 2007 (Figure 8b). Relative concentration peaks were present around the end of March, mid-April (but a bit earlier in 2007) and then steadily increased after the end of May (Figure 7 and Figure 8). Such oscillations appeared at least in part controlled by the tidal motion (see enclosed videos). The body length distribution of cod larvae in the western, central and –eastern parts of the North Sea and in the Skagerrak (Figure 9 - 12) was in the range 8 - 38 mm in May and 18 - 60 mm in June, which was well in agreement with that observed by Nielsen and Munk (2004). In two consecutive surveys in 2001, authors reported a size distribution in April-May of 6.3 mm - 36.5 mm and in May-June of 9.3 mm -57.3 mm, the latter being larger than the size distribution obtained with our model. Variability in size distribution between different areas of the North Sea was always present (Figures 9, 10, 11, and 12), but in 2006 and particularly in 2007, this variability appeared to be of reduced intensity.

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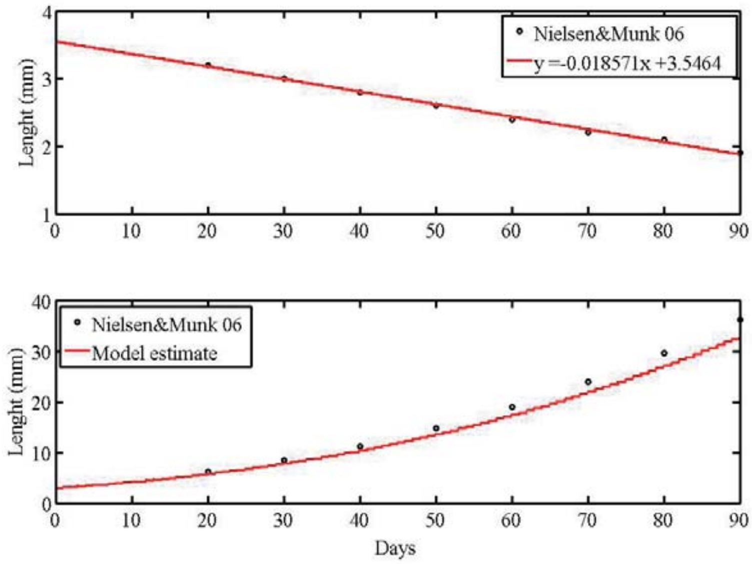


Figure 1: Curve fitting of the growth rate (upper panel) and length (lower panel) data from Nielsen and Munk (2004).

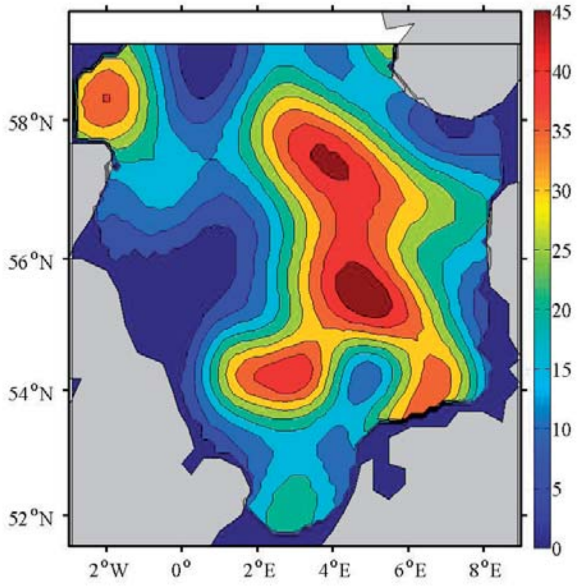


Figure 2: Distribution of the spawning areas and number of particles released per box (total # particles ~100,000)

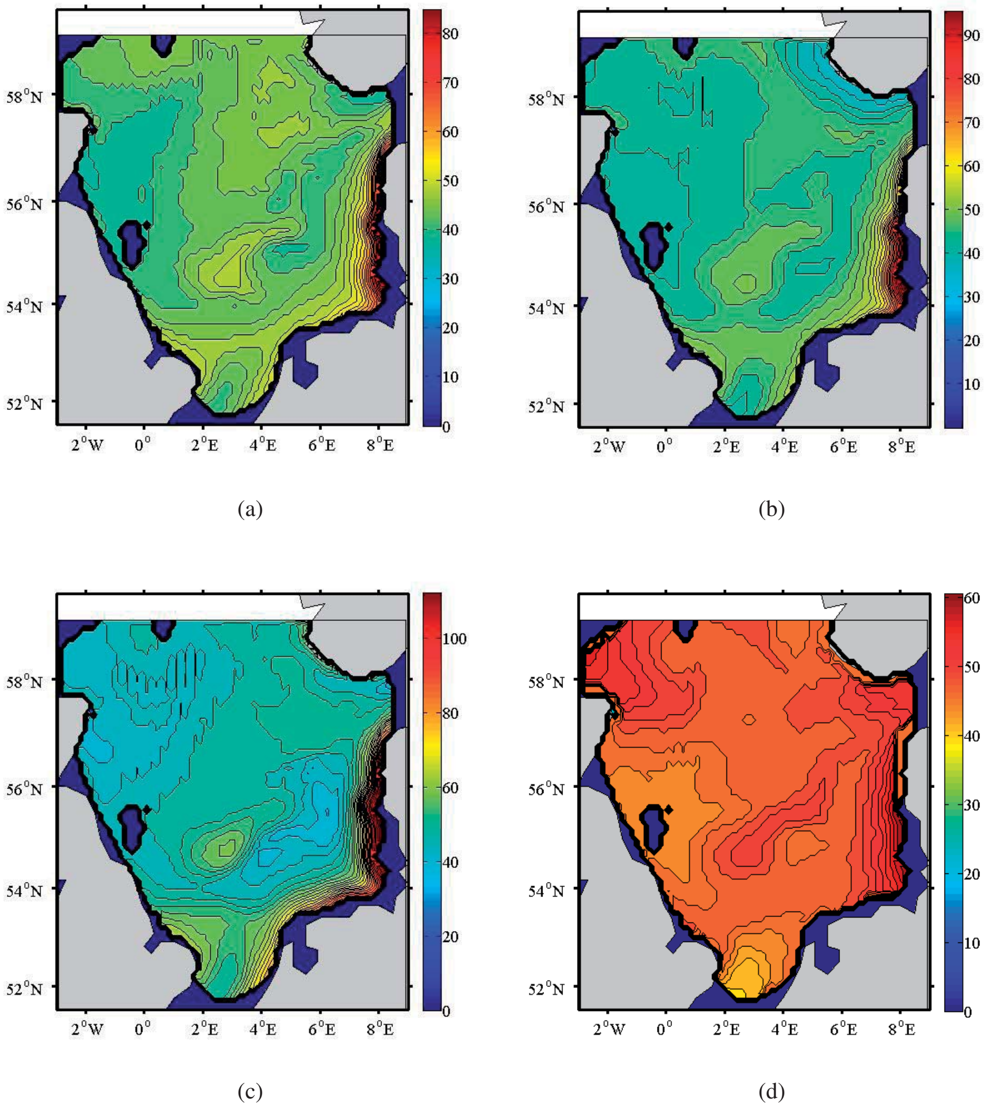
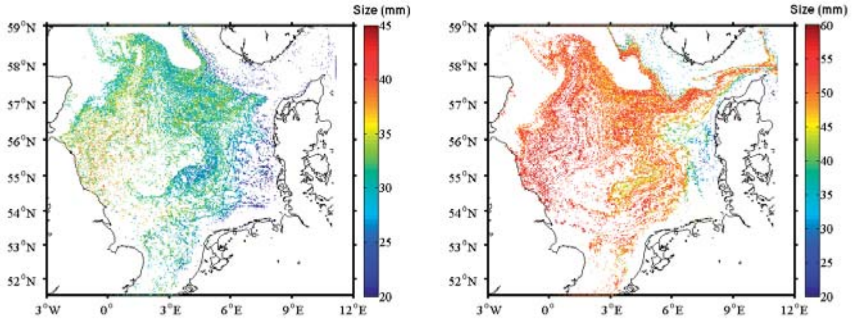
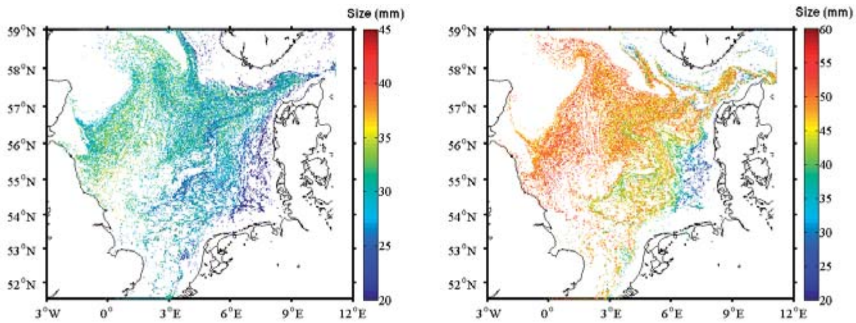


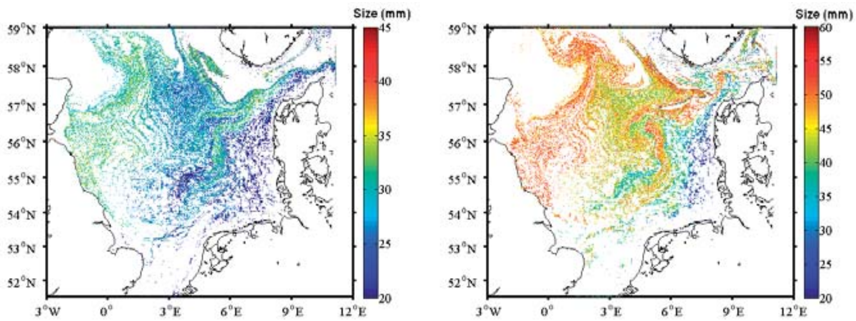
Figure 3: Simulated spawning dates for cod in the North Sea in (a) 2004 (b) 2005 and (c) 2006 (d) 2007 (color in calendar days).



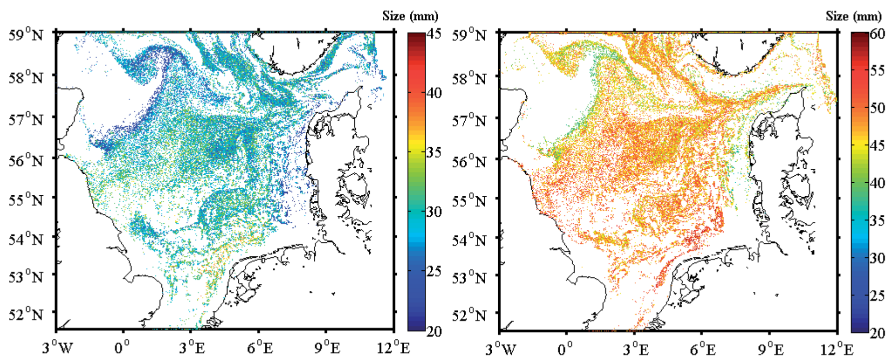
(a) 2004



(b) 2005



(c) 2006



(d) 2007

Figure 4: Simulated larvae distribution and size in May (left panels) and June (right panels) (a) 2004 (b) 2005 (c) 2006 (d) 2007.

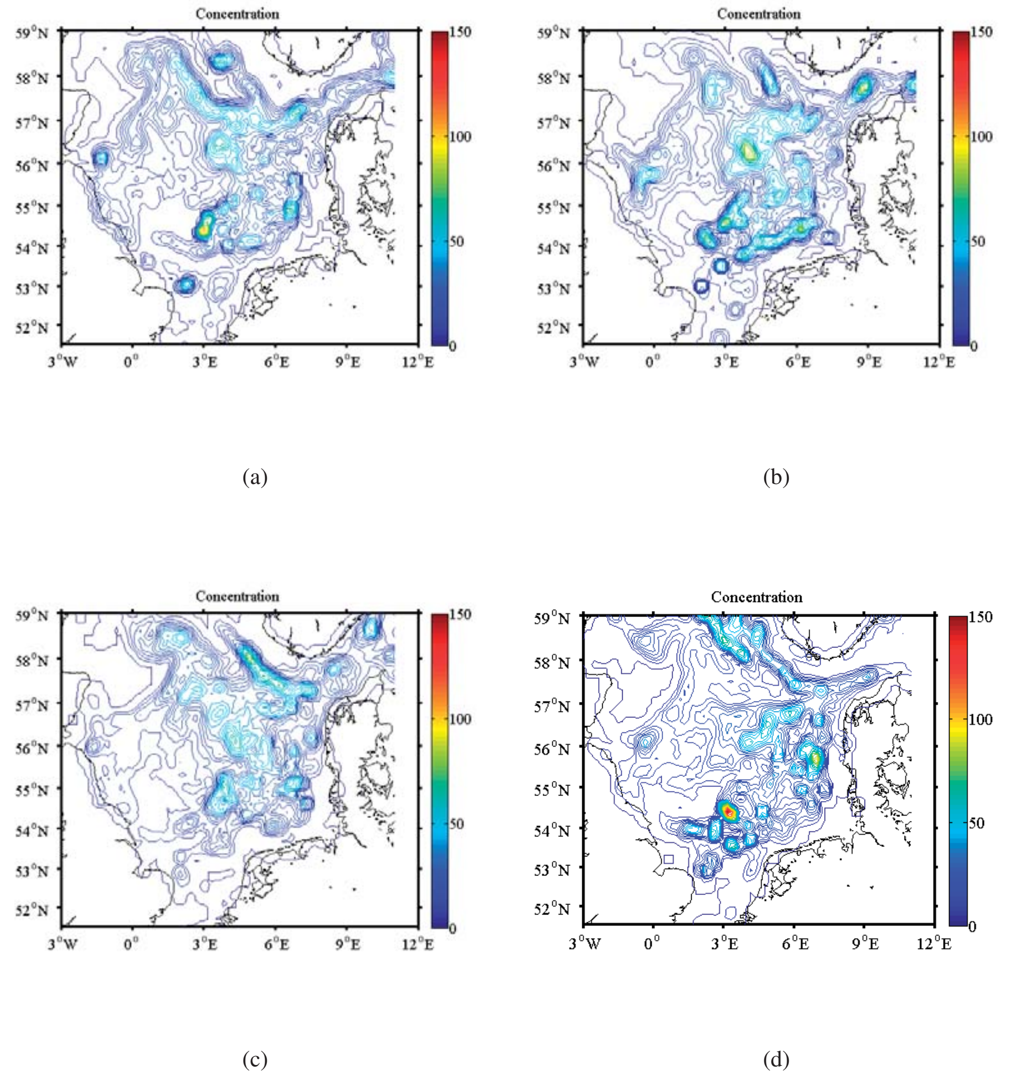
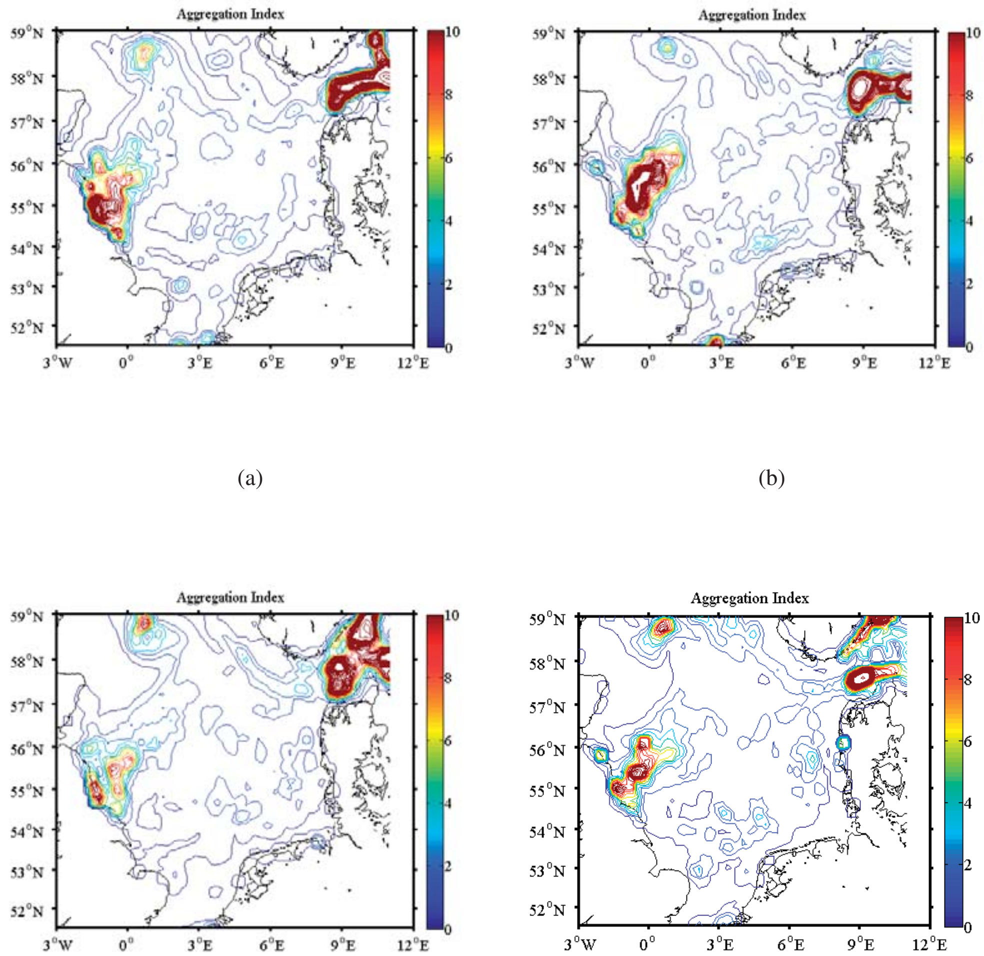


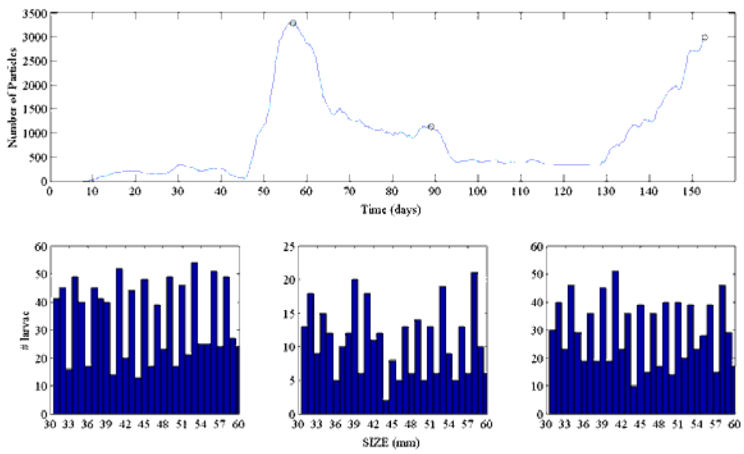
Figure 5: Map of the relative concentration of larvae in the study area on the 30th of June (a) 2004 (b) 2005 (c) 2006 (d) 2007. Reported colors are the number of particles in the specific area.



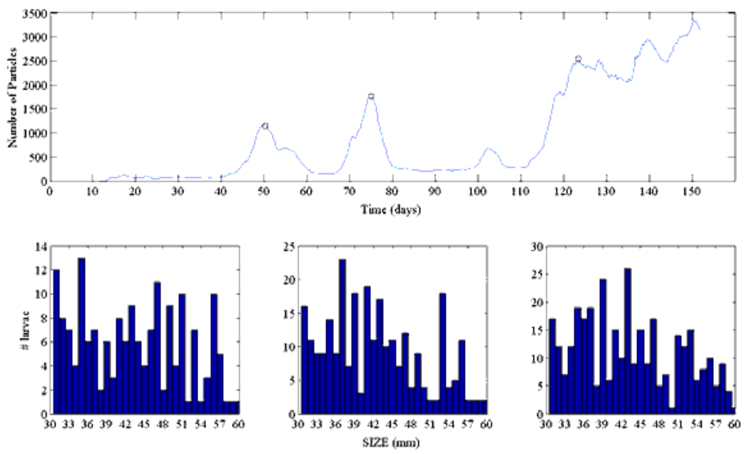
(a) (b)

(c) (d)

Figure 6: Map of the aggregation index on the 30th of June (a) 2004 (b) 2005 (c) 2006 (d) 2007.

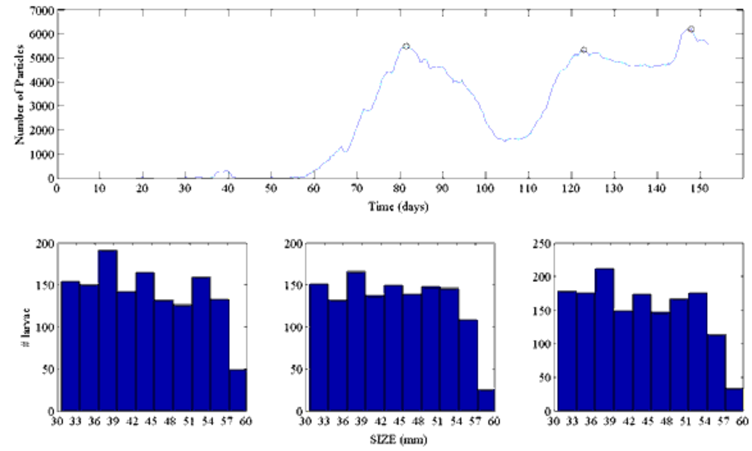


(a)

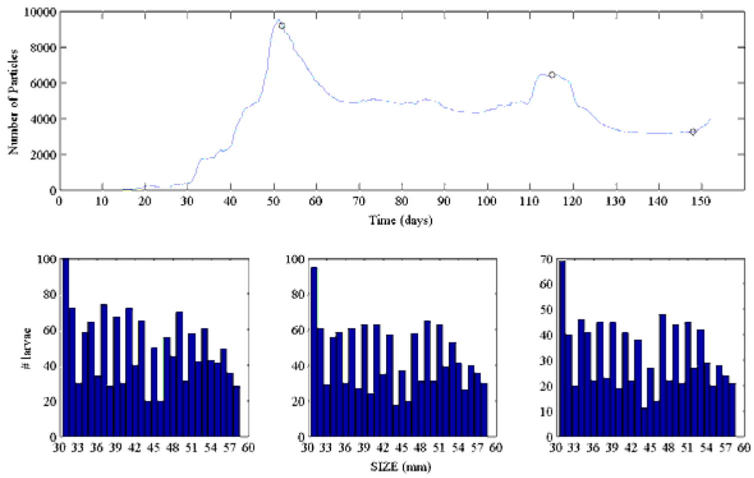


(b)

Figure 7: Upper panel: Number of larvae in the Skagerrak (>57N, >8.6E) from the 29 Jan (day 0) to the 30 of June (day 150) in (a) 2004 and (b) 2005. Lower Panels: larval size distribution for the three peaks in abundances indicated in the upper panel.

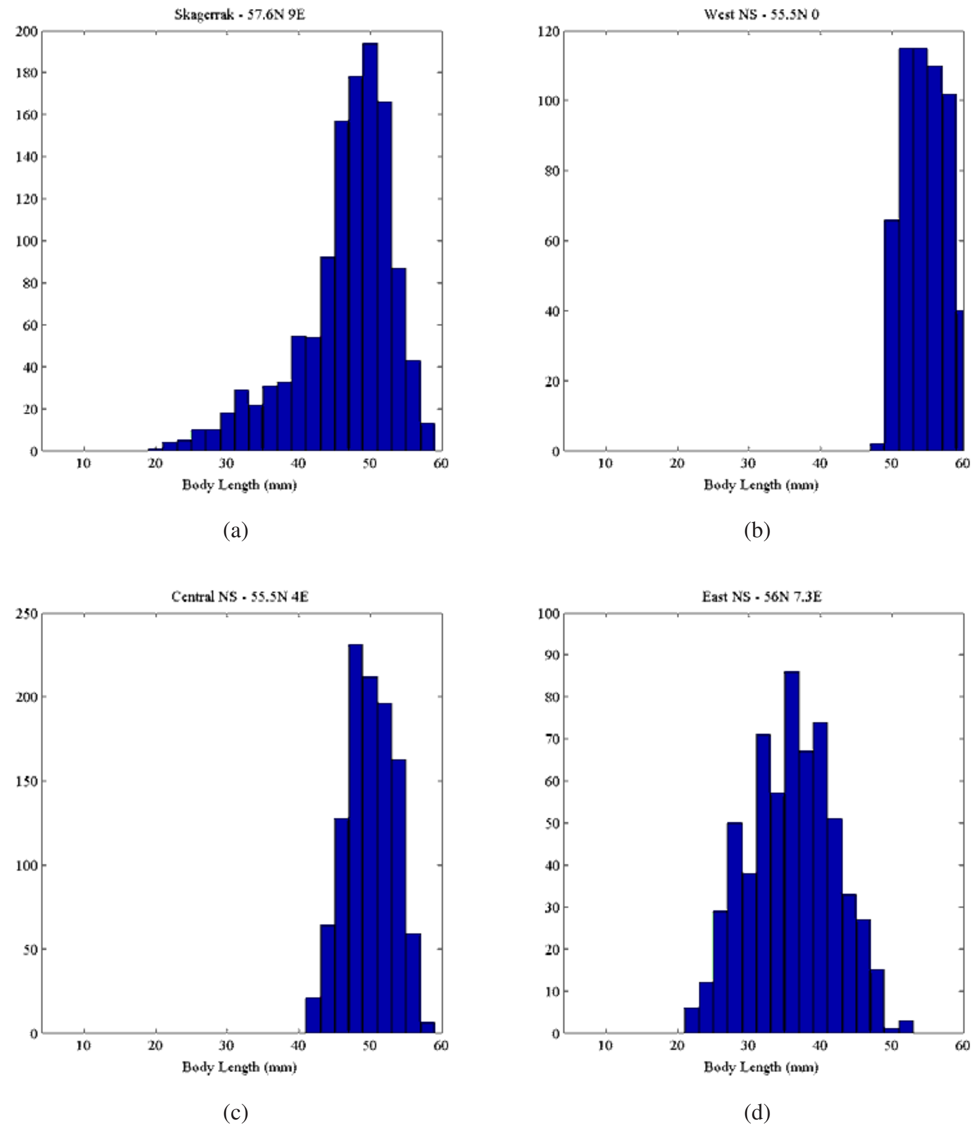


(a)



(b)

Figure 8: Upper panel: Number of larvae in the Skagerrak (>57N, >8.6E) from the 29 Jan (day 0) to the 30 of June (day 150) in (a) 2006 and (b) 2007. Lower Panels: larval size distribution for the three peaks in abundances indicated in the upper panel.



(a) (b) (c) (d)

Figure 9: Simulated size distribution of cod larvae on the 30th June 2004 for four different regions (a) Skagerrak (b) western North Sea (c) central North Sea (d) eastern North Sea.

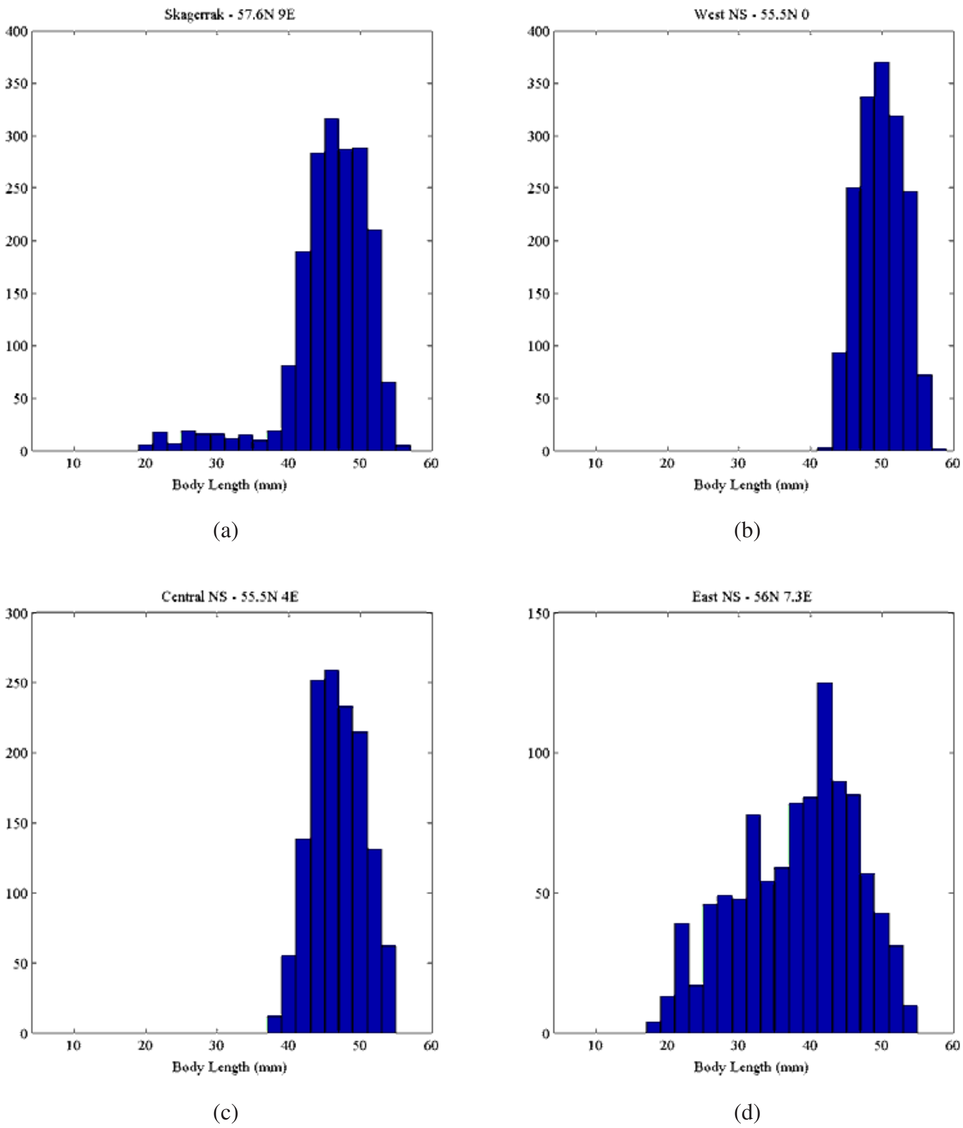


Figure 10: Simulated size distribution of cod larvae on the 30th June 2005 for four different regions (a) Skagerrak (b) western North Sea (c) central North Sea (d) eastern North Sea.

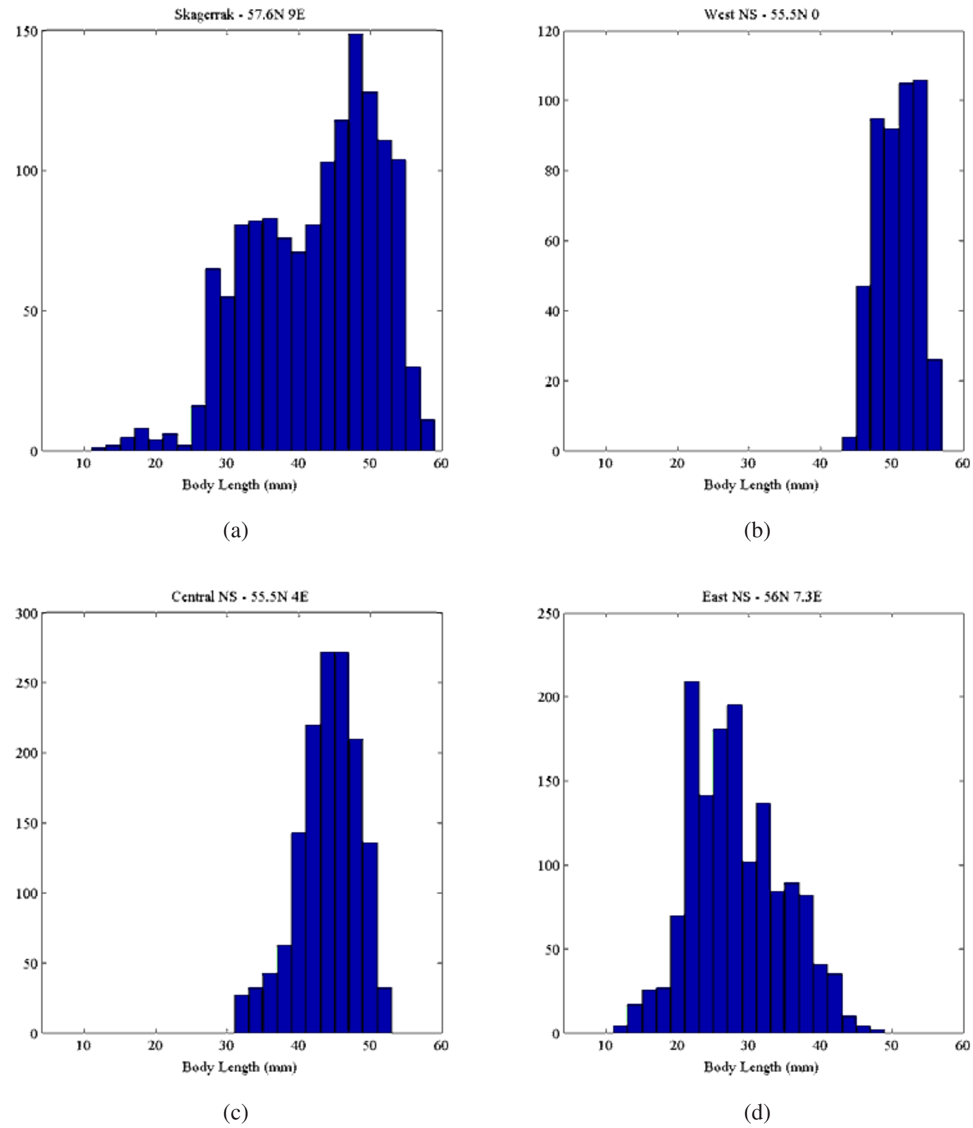


Figure 11: Simulated size distribution of cod larvae on the 30th June 2006 for four different regions (a) Skagerrak (b) western North Sea (c) central North Sea (d) eastern North Sea.

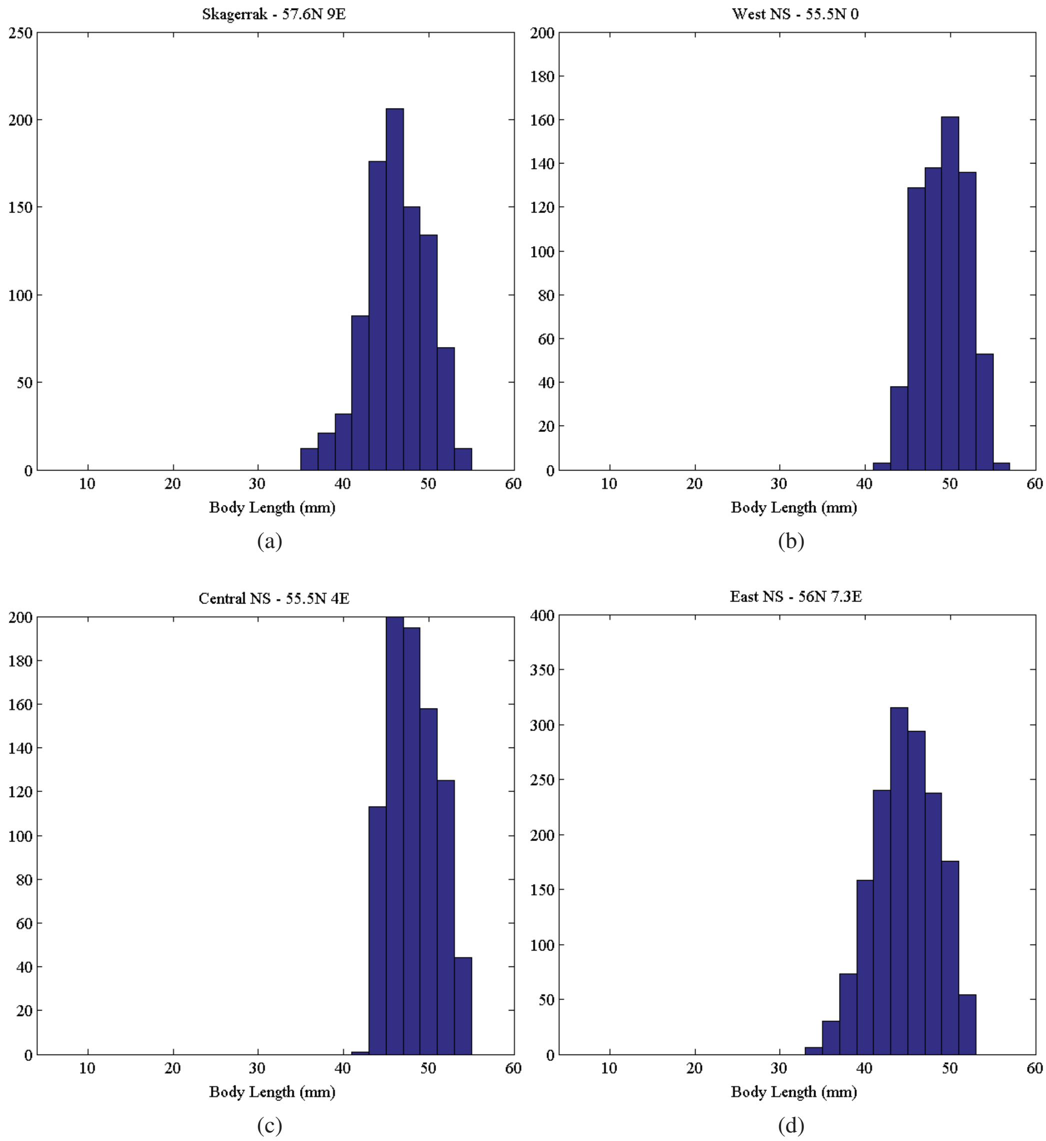


Figure 12: Simulated size distribution of cod larvae on the 30th June 2007 for four different regions (a) Skagerrak (b) western North Sea (c) central North Sea (d) eastern North Sea.

Work package E3

Growth dynamics of Atlantic cod

by Karin Hüssy

Introduction

Growth patterns are genetically programmed, but growth rates are still highly variable among individuals and stocks. The primary drivers for this variability are environmental variables such as temperature and food availability. Many other characteristics of the fish, such as metamorphosis, sexual maturity etc., depend on growth rates and thus attaining a given size (Dutil & Brander, 2003). Consequently, changes in growth rate and any factor affecting growth can have profound impacts on cod recruitment, distribution and fishery yields (Krohn *et al.*, 1997; Swain *et al.*, 2003). Over the life of the fish, the pattern of energy allocation changes with increasing age and size.

Individual cod occupy a wide range of habitats, each with seasonal and inter-annual variations in environmental conditions. Contributing to the variability in the surrounding element are seasonal migrations and habitat specific prey organisms which also are subject to spatio-temporal variability in abundance. All these factors in combination result in variable growth patterns, which in turn may have impact on reproduction and mortality.

In this paragraph, preliminary patterns of growth trajectories in the Skagerrak area are examined to examine the variability thereof between years, year classes and geographical areas.

Overview over samples

For estimating growth of fish, the most essential parameters are size (length and/or weight) and age. Unfortunately, no age estimates are available for the fish sampled during the OSkar project. Instead, samples from routine discard samplings were selected (SEAS data), where all individual data (length, weight, age, catch position and date) are available except for sex and maturity. An overview over available samples is given in Table 1 and Table 2. InTable 2 and all further analyses, age classes 5 and 6 were omitted, since there was only one fish of age 6 (none of age 5).

Table 1. Number of samples, age- and size range for each year.

Years	fish (*n*)	size range (mm)		age range (y)
2008	528	160 -	540	1 - 4
2009	1485	120 -	970	0 - 6
2010	1012	150 -	550	1 - 3

Table 2. Numbers at age per quarter and year.

Year	Quarter	Age				
		0	1	2	3	4
2008	1	0	0	113	24	1
	2	0	27	107	63	1
	3	0	111	12	0	0
	4	0	33	36	0	0
2009	1	0	20	68	55	0
	2	0	251	158	42	5
	3	1	330	36	2	1
	4	40	700	30	0	0
2010	1	0	32	100	46	0
	2	0	236	278	25	0
	3	0	455	88	0	0
	4	0	108	35	0	0

Analyses, results and conclusions

Cod eggs are spawned in the water column and develop over the course of approximately 3 months from egg to different larval stages to the pelagic juveniles. During these early life stages the fish are subject to entrainment of water currents which may retain or transport them away from the spawning areas. At a size of approximately 5 cm, these juveniles settle into the demersal habitat, a change in habitat choice that is accompanied by a change in food selection and may also include considerable changes in environmental temperature. The shallow nearshore areas thus serve as nursery areas for demersal juvenile stages, while the further offshore areas are known feeding and spawning area. Juvenile cod are known to remain relatively stationary in the coastal nurseries during their first 1-2 years of life, when they gradually move to deeper waters and start to take part in the spawning/feeding migration of the adult stock component.

Differences in growth dynamics are a good indicator for a habitat's suitability as nursery area. In the following, differences in growth between three different areas was examined with the objective to identify the geographical area that promotes highest growth rates and to estimate at what age and time of the year juvenile cod in the Skagerrak area leave their nursery areas. Due to the relatively limited sample size, the area was divided into three areas, a western area (west of 9^{o} longitude), an eastern area (east of 10.2^{o} longitude) and an intermediate area between these as shown in Figure 1.

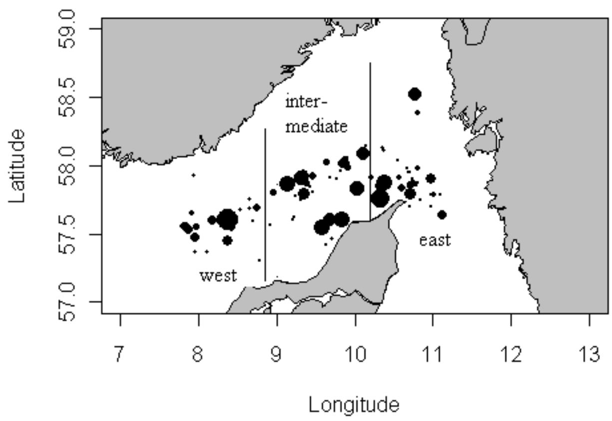


Figure 1. Map of Skagerrak, with sample locations indicated with black circles, and circle size representing sample size. Area boarders used in the analyses of geographical analyses are indicated with vertical lines.

Analyses

Absolute growth was analysed as average size at age for each age class separately. Only age classes 1, 2 and 3 were represented in sufficient sample sizes to allow any statistical analyses. Analyses were carried out using either samples from individual years or following a specific year class. The latter implies using data from different years, for the 2007 year class e.g. age 1 data from 2008, age 2 data from 2009 and age 3 data from 2010. Data were tested with generalised linear regressions and one-way/two-way ANOVA.

The following analyses were carried out:

1) The influence of geographical area was examined together with the effect of sampling year and quarter
2) The influence of year and area on average size for fish caught during the first quarter (Q1), which correspond to the spawning season
3) Comparison of the 2007 year class between the three areas
4) Year class effects

Results

Effect of geographical area, including all years and quarters

Within each of the three age classes there were significant effect of quarter and year (Table 3). The only exception was age 3, where the quarter effect was not significant. In order to avoid a possible bias in year effects due to the somewhat unbalanced sample sizes (Table 2), only data from the first quarter was used for the following analysis.

Table 3. Statistical analysis of area, year and season effects on size at different ages.

Age	Area	Year	Quarter
1	***	***	***
2	*	***	***
3	***	**	ns

p values: ns= not significant, * < 0.05, ** < 0.01, *** < 0.001

Effect of geographical area for the first quarter

For all age classes there were significant area effects on average size from the first quarter, with fish from the east being significantly smaller in all year/age class combinations than those from the western and intermediate areas. Significant differences between years were also observed except for age class 2. For age classes 1 and 2 growth was considerably smaller in 2008 than in the two subsequent years, while age class 3 had the smallest size in 2010. For age class 1 this shows that the year class 2007 had slowest growth, which is consistent with age class 3, where the smallest size occurred in 2010 (also representing the 2007 year class). But age class 2 is not consistent in that it for all areas is the 2007 year class (age 2 in 2009) that showed the largest size. No apparent reason for the non significant year effect is evident.

Table 4. Average size at age per year and area.

		Area				
Age	Year	E	IM	W	p_{year}	p_{area}
1	2008	190	198	225	**	***
	2009	229	245	234	**	***
	2010	228	252	235	**	***
2	2008	240	308	334	ns	***
	2009	336	357	358	ns	***
	2010	311	353	309	ns	***
3	2008	385	452	408	**	***
	2009	386	490	410	**	***
	2010	368	393	370	**	***

Area: E = eastern, IM = intermediate, W = western
p values: ns= not significant, * < 0.05, ** < 0.01, *** < 0.001

Inferior growth conditions not only manifest themselves in smaller size at age but also a lower physical condition factor. One of the most common condition factors used is the Fulton K which is calculated as (weight/length^3)*100. To evaluate whether the observed differences in size at age were linked to inferior growth conditions in general or possibly attributable to other factors, the Fulton K factor was analysed. With a few exceptions, all average condition factors were above 1, indicating that fish were in good condition (

Table 5). This analysis also showed that even though fish from the eastern areas had a smaller size at age, their condition was not significantly lower than in fish from more western areas.

Table 5. Average Fulton K's condition factor per age class, year and area.

Age	Year	Area E	IM	W	p_{year}	p_{area}
1	2008	1.14	0.98	1.04	ns	ns
	2009	1.01	1.09	1.05	ns	ns
	2010	1.11	1.01	0.93	ns	ns
2	2008	1.01	1.08	1.07	ns	ns
	2009	1.09	1.03	1.08	ns	ns
	2010	1.07	1.07	1.02	ns	ns
3	2008	1.05	1.16	1.11	***	ns
	2009	1.10	1.04	1.14	***	ns
	2010	1.08	1.07	1.01	***	ns

Area: E = eastern, IM = intermediate, W = western
p values: ns= not significant, * < 0.05, ** < 0.01, *** < 0.001

Effect of geographical area on year class 2007

The year class 2007 is the one best suited to examine the effect of area on individual year classes. The 2007 year class is represented as age 1 in the 2008 samples, as age 2 in the 2009 samples and as age 3 in the 2010 samples. The growth curve follows the typical von Bertalanffy growth (
Figure 2) and confirms the results of the yearly samples in Table 4. Size at age is largest in the western and intermediate areas and slowest in the eastern. The difference in average size is remarkable constant throughout the age 1 and until the 2. Quarter of age 2. Thereafter, size at age is highly variable without any consistent pattern.

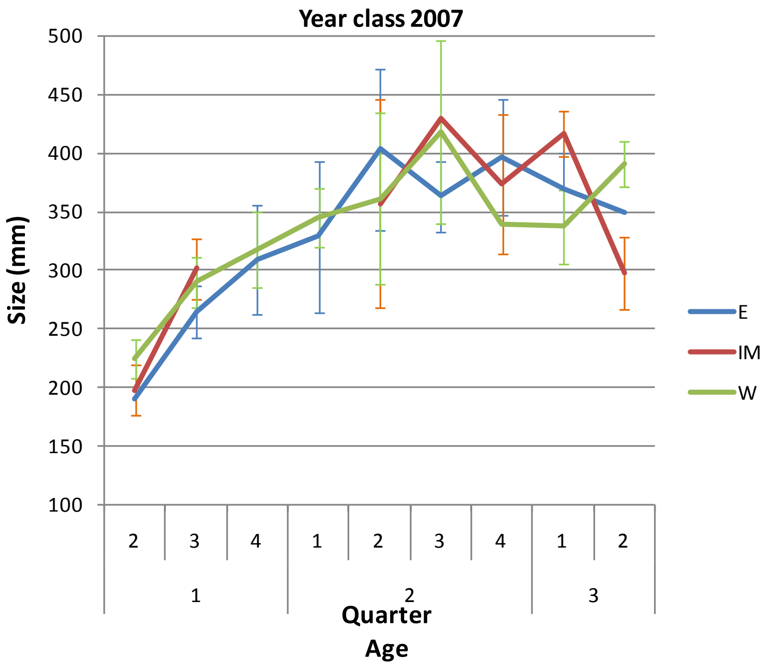
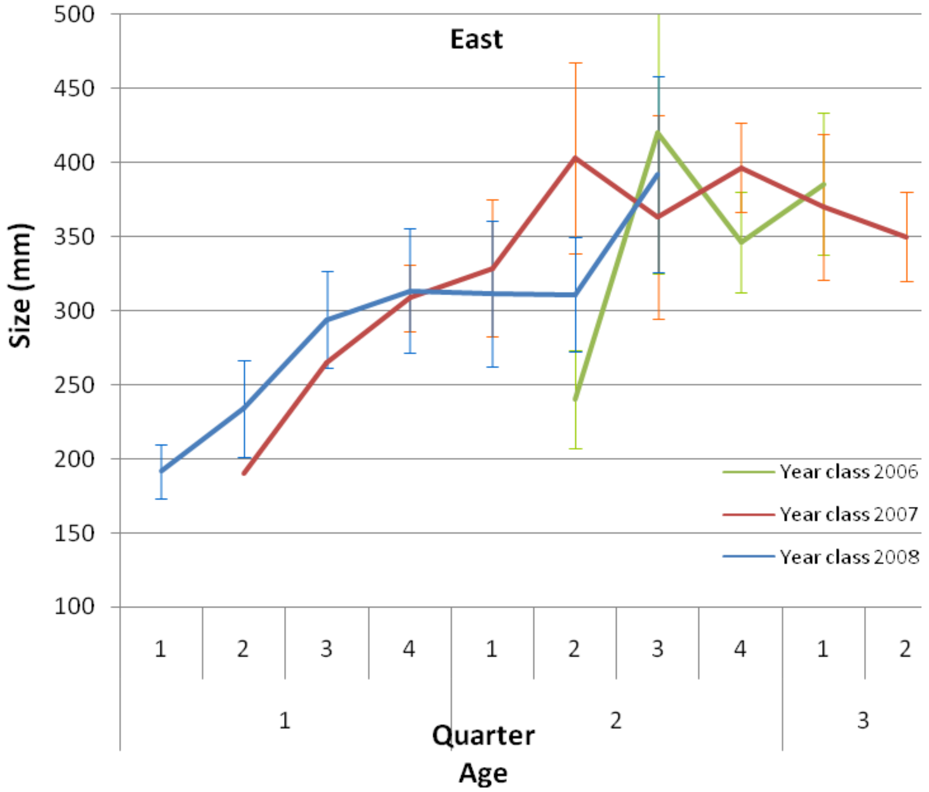
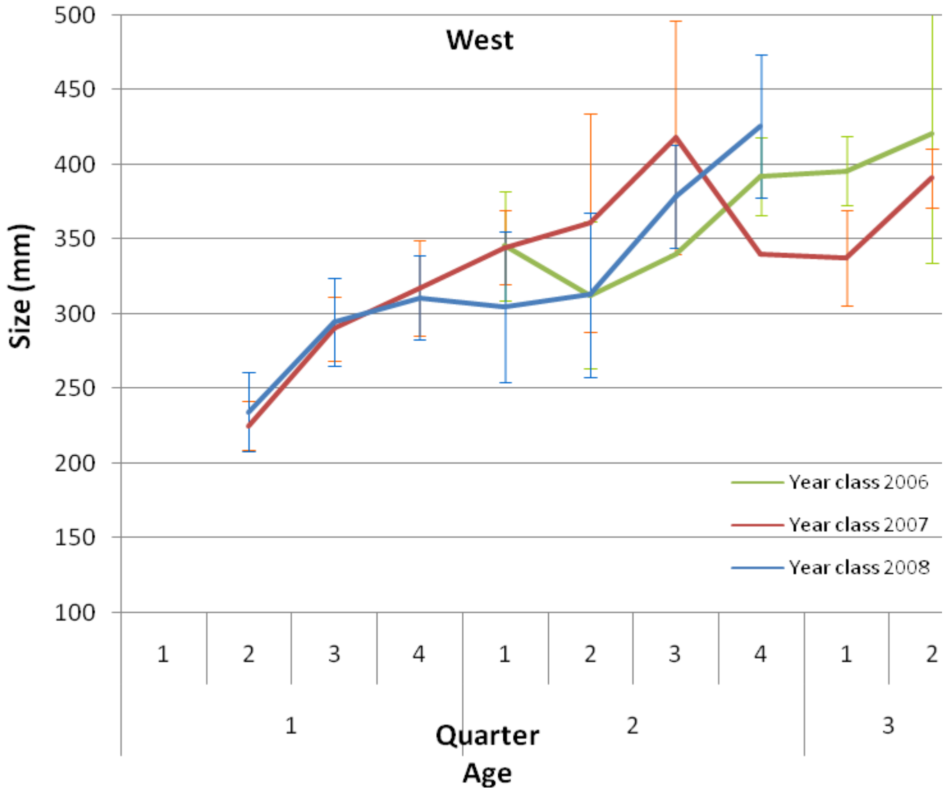


Figure 2. Growth curves (average ± standard deviation) for the 2007 year class observed in three different areas of the Skagerrak. E = east, W = west and IM = intermediate. The x-axis represents the four quarters (upper labels) within each year of life (= age, lower label) for that year class.

Year class effects

Three different year classes (2006, 2007 and 2008) were followed over the quarters of one year, and the subsequent year. Due to the limited sample size with respect to years, only one year class (2007) is represented with three subsequent age classes (age-1 in 2008, age-2 in 2009 and age-3 in 2010). The growth curves show limited variability around the average at age 1 for all year classes and areas (Figure 3). From the first quarter of age 2, variability increases both between year classes, but also within individual year classes. From that age, size at age is without a consistent pattern, increasing and decreasing at random. The lowest degree of inter-year class variability occurred in the western area.


East
Size (mm)
500
450
400
350
300
250
200
150
100
Year class 2006
Year class 2007
Year class 2008
1 2 3 4 1 2 3 4 1 2
1 2 3
Quarter
Age


West
Size (mm)
500
450
400
350
300
250
200
150
100
Year class 2006
Year class 2007
Year class 2008
1 2 3 4 1 2 3 4 1 2
1 2 3
Quarter
Age

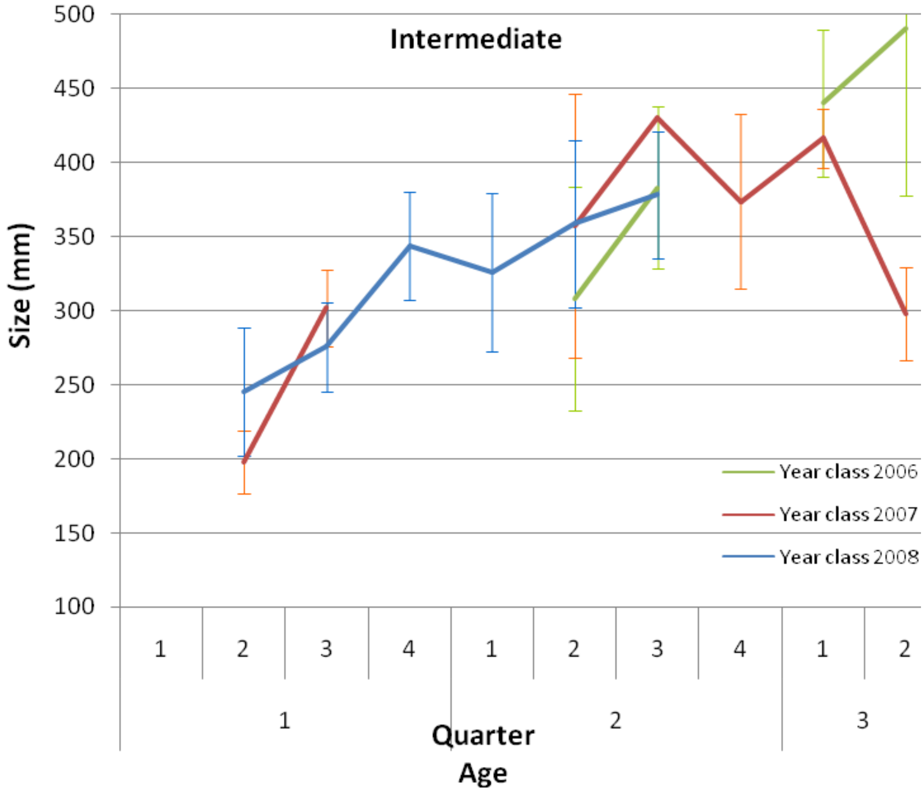


Figure 3. Growth curves (average ± standard deviation) for the year classes 2006, 2007 and 2008 in relation to the three different geographical areas. The x-axis represents the four quarters (upper labels) within each year of life (= age, lower label) for that year class.

Conclusions

Effect of geographical area, including all years and quarters

The effect of quarter is not surprising since it represent growth over the season, where cod gain most of their annual growth during the spring and summer months. In order to Year effect possibly may originate from the somewhat unbalanced sample sizes in relation to quarter only size at age during Q1 was analysed.

Effect of geographical area for the first quarter

There seems to be a general area effect on size at age with slowest growth rates in the eastern areas of the Skagerrak, intermediate growth rates in the western areas and fastest growth rates in between. Since the same general trend of smaller size at age in samples from the eastern area were observed, it doesn’t seem likely that this observation is simply attributable to sampling artefacts. There are two possible explanations for this observation. 1) The samples represent different cod stocks with different growth dynamics and 2) Eastern areas are less suitable as nursery areas for juvenile cod. The analysis of the condition index Fulton K shows gives an indication of feeding conditions in the respective areas. Generally, values of Fulton K < 0.8 are associated with poor condition cod while values of K > 1.0 are associated with cod in good condition (Marteinsdottir & Begg, 2002). This suggests that the condition of the average cod from this study was exceptionally good. As with growth, inter annual variations can be expected, particularly in the age classes when individuals have started to participate in spawning. Gutted weight was not available, so that sampling in relation to the spawning process may introduce considerable bias. The analysis of the condition index shows that even though cod in the eastern areas were smaller at a given age they did not have a concurrently lower condition than in the western areas. Their physical condition is just as good as in those from the other areas. This suggests that the eastern areas do not seem to be inferior nursery areas through limitation of food supply. Environmental conditions may have an influence through e.g. lower environmental temperature which limits growth. However, temperature regimes do not seem to be highly different (Figure 4). This figure only shows that average monthly temperatures within the sampling areas do not differ considerably between areas. This does not exclude the possibility that temperature regimes may vary on a smaller local scale. But it seems unlikely that temperature related growth differences occur within the Skagerrak area. The Skagerrak is a mixing area where a range of local stocks and North Sea as well as Kattegat stocks may possibly occur. Discerning between different cod stocks would require genetic analyses and is not possible with the present samples.

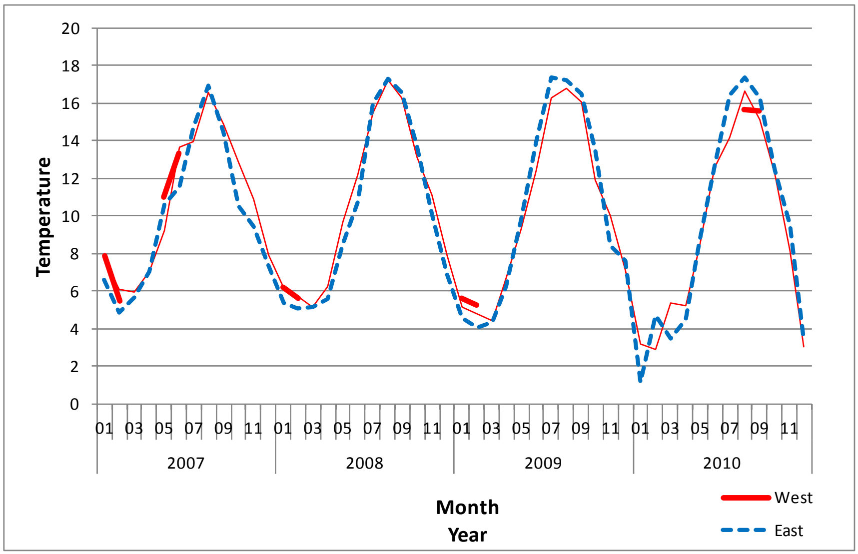


Figure 4. Average monthly temperature fluctuations in the western and eastern areas where samples originated from. For the western area only data marked in bold was available. Thin red line indicates seasonal temperatures in Marsden Squares 98388, the square within which the western area is situated (from the ICES Oceanographic database).

Effect of geographical area on year class 2007

Following the growth of one year class (2007) shows the same pattern with larger size at age throughout all quarters of the second year (age 1) and into age 2. During summer of the third year of life (age 2), the consistent pattern breaks up, variability increases and growth curves cross each other. This growth pattern is consistent with the observation of tagged individuals from other areas: Juvenile cod in the Skagerrak area remain stationary from the time of settlement at age 0 throughout the subsequent years to an age of 2 years. The increased variability thereafter suggests increased exchange between areas. Since the significant area effect found above persists throughout all ages and years, this suggests that east-west migrations are not extensive.

Year class effects

The Skagerrak is a highly dynamic area, where the hydrographical conditions strongly depend on wind forcing and ocean currents. As a possible consequence thereof the environmental conditions may be highly variable. This is evident from the large variability in growth trajectories of individual year classes of cod. In all areas, variability within and between year classes is smallest during the second year of life (age 1). This seems to be attributable to a relatively stable environment in the nearshore nursery areas. During their third year of life cod move into deeper waters and start taking part in feeding- and spawning migrations. The high degree of variability as well as the rising and falling average size at age seems to indicate that there is a considerable degree of migrations in this area and that fish do not necessarily return to their origins.

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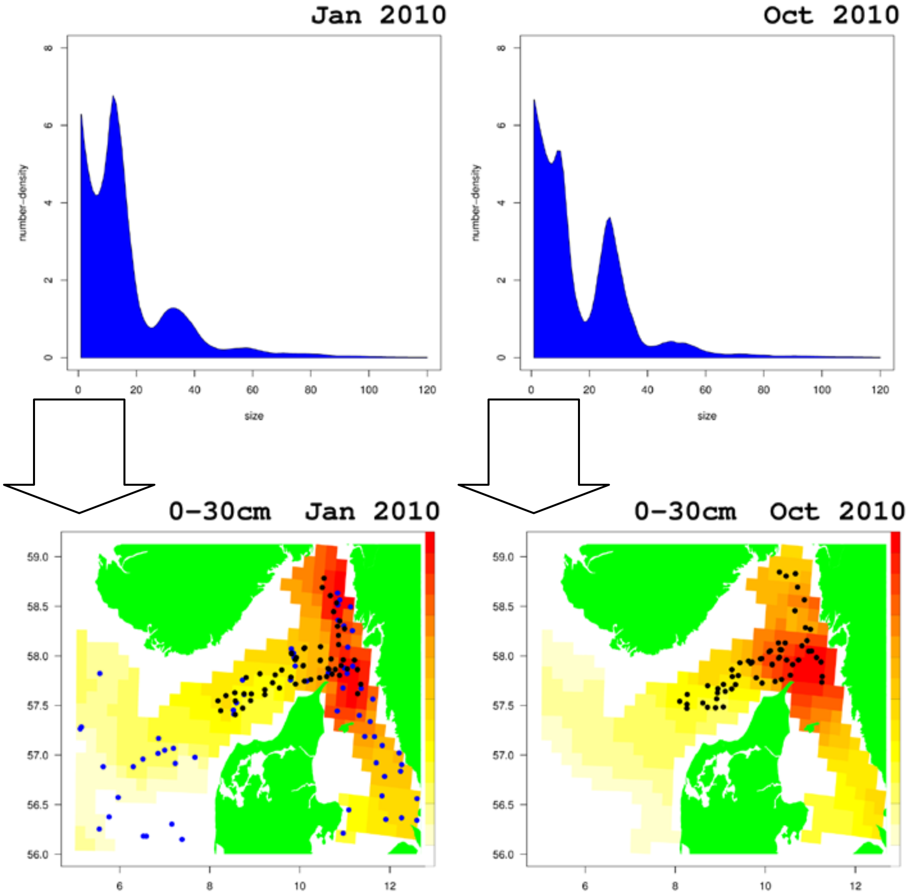
Work package F

Geostatistical Population Model (GeoPop)

by Kasper Kristensen



GeoPop

Contents

1 Building a random field model

Length frequency data obtained from individual hauls are naturally described using a top-down approach, starting from the largest spatial scale down to the local spatial scale:

1. Consider a dynamic model of the entire population indexed by size and time $n(s, t)$.
2. Distribute individuals randomly in space in a way such that the density varies continuously as function of size, space and time.
3. Add size-continuous noise for each sample to account for fish shooling and other small-scale behaviour related to fish size.
4. Add gear selectivity.

In the following sections we describe how each of these four processes are modelled.

1.1 Process 1: The size spectrum

The perhaps simplest possible size spectrum model assumes constant total motality z, growth rate g and recruitment rate r. These assumptions imply the following PDE for the log-number-density $\phi(s, t)$:

$$\dot{\phi}(s, t) = -g\nabla_s \phi(s, t) - z$$

with boundary condition $\phi(0, t) = \log r - \log g$.

Obviously this model is un-realistic on a long term scale because of the assumptions about the parameters being constant as function of time and size. Traditional model approaches would attempt to circumvent these issues by adding further biological complexity to the model. For instance by allowing the recruitment to be time dependent or letting the growth and mortality be size dependent. To avoid overly involved nonlinear model formulations we instead propose the following simpler strategy: Even though the above von Foerster PDE is unrealistic on a long temporal scale it is not to bad on a short temporal scale. We therefore choose to add noise to the PDE in each time-step:

$$\dot{\phi}(s, t) = -g\nabla_s \phi(s, t) - z + \varepsilon(s, t)$$

and thereby account for the model weakness.

- By adding $\varepsilon(s, t)$ the size-spectrum has become a stochastic process.
- The model has 4 parameters: z, g, r and noise variance.
- Recuitment peaks will be contained in the noise term. When the model is fitted to data the recruitment peaks will propagate through the spectrum.
- Here is a simulation of the process started in the stationary initial distribution:

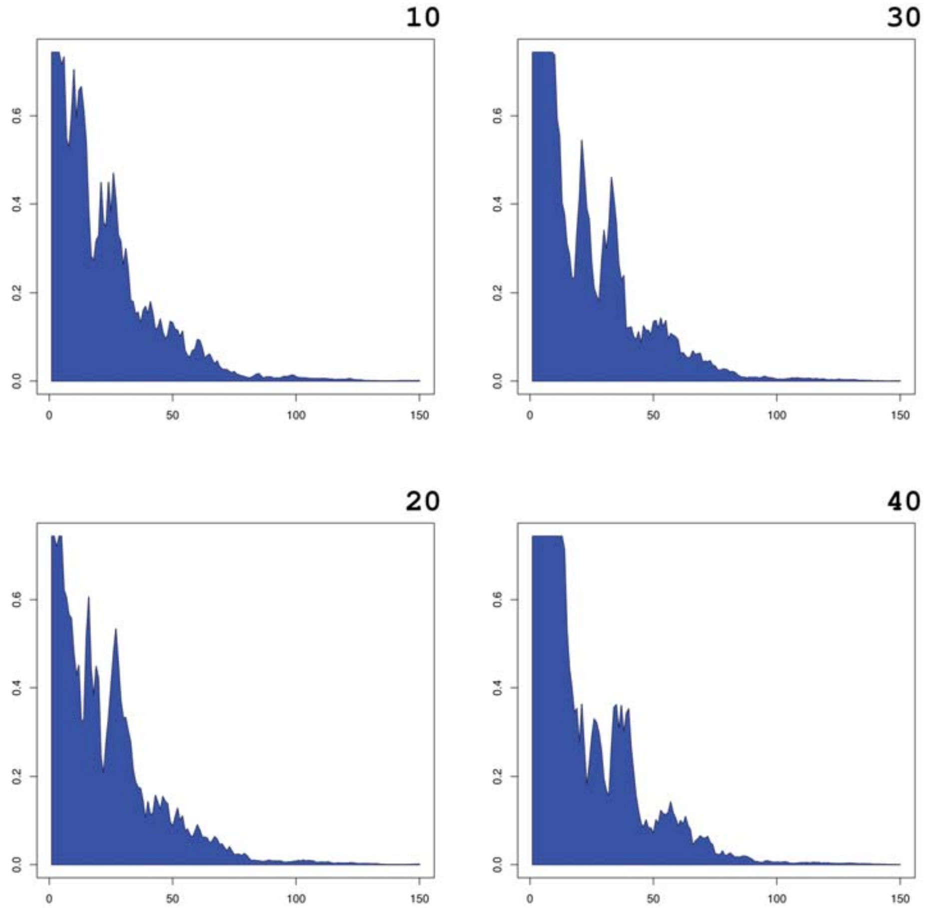


Figure 1: A stochastic simulation from the SPDE description of the size spectrum (von Foerster PDE with random noise added in each time step). Note how it is possible to follow the movement of the peaks between the different times.

1.2 Process 2: Spatial surfaces

The second step is to distribute the size spectrum across the spatial grid. For any size-space-time-coordinate (s, x, t) let $\eta(s, x, t)$ denote the deviation from the population mean $\phi(s, t)$. This residual is expected to be continuous in (s, x, t) and the "degree of continuity" must be estimated. We assume a separable correlation of the form

$$\text{corr}(\eta(s,x,t), \eta(s+\Delta s, x+\Delta x, t+\Delta t)) = \\ \rho_{\text{size}}(\Delta s)\rho_{\text{space}}(\Delta x)\rho_{\text{time}}(\Delta t)$$

Each of $\rho_{\text{size}}(\Delta s)$, $\rho_{\text{space}}(\Delta x)$ and $\rho_{\text{time}}(\Delta t)$ are chosen as correlations of Markov processes.

1.3 Process 3: Small scale variations

Even for close cordinates (x, t) two different hauls with identical gears can show very different size-distributions. This is taken care of by adding a further layer of noise $\eta_0(s, x, t)$ with correlation

$$\rho_0(\Delta s, \Delta x, \Delta t) = 1_{(\Delta x = \Delta t = 0)}\rho_{size}(\Delta s)$$

i.e. a size-correlated nugget effect. This process is independent between samples and therefore only works within hauls. It generates "within-haul size-correlation" which is expected for instance due to size-dependent schooling.

1.4 Process 4: Gear selectivity

Gear selection is defined as the conditional probability a fish of size s gets caught given its presence within the trawl. A sigmoid parameterization is used:

$$\mathrm{sel}(s) = \frac{1}{1 + 3^{-\frac{2}{SR}(s - l_{50})}}$$

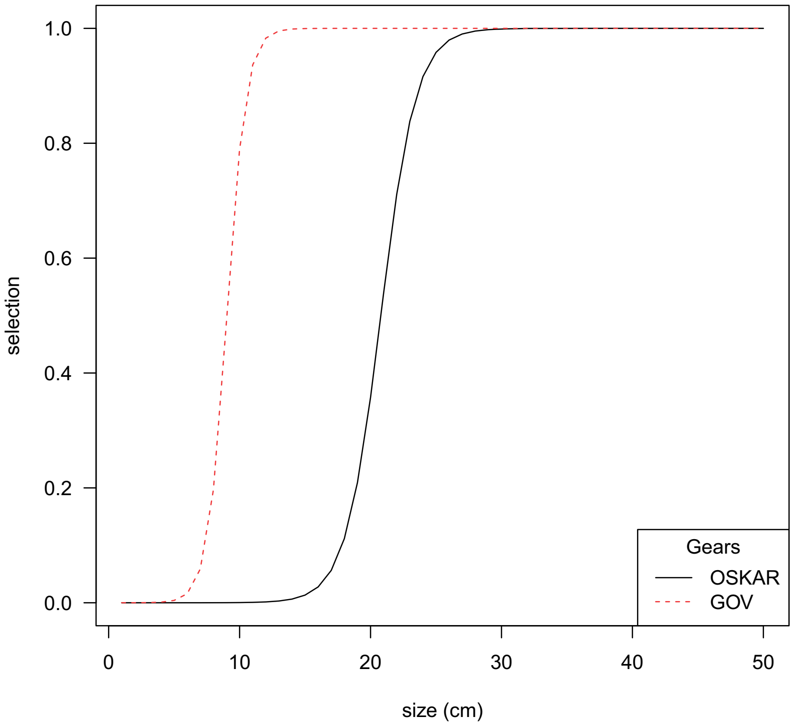


Figure 2: Estimated gear selection curves of GOV (red) and OSKAR (black).

1.5 1-4: Putting it all together

The four contributions are added to form the overall model of observed size distributions:

$$\begin{aligned}
\log \mathrm{density}(s, x, t) &= \sigma_1 \phi(s, t) && \text{(Process 1)} \\
&+ \sigma_2 \eta(s, x, t) && \text{(Process 2)} \\
&+ \sigma_3 \eta_0(s, x, t) && \text{(Process 3)} \\
&+ \log \mathrm{sel}(s) && \text{(Process 4)}
\end{aligned}$$

$$\text{count-within-haul} \sim \mathrm{Poisson}(\exp(\text{log-density}(s, x, t)))$$

- Process 1+2 represents the hidden surface
- Process 3+4 represents the measurement noise

2 Model fitting

2.1 OSKAR and GOV

Here is an overview of the model parameters of the individual four processes in the case of two gears OSKAR and GOV:

1. The size spectrum: Four parameters - growth, mortality, recruitment and noise variance.
2. The large scale spatio-temporal field: Four parameters - time-correlation, spatial correlation, size-correlation and variance.
3. The small scale variability: One parameter - the variance.
4. Gear selection: Five parameters - $L50$ and SR for each gear plus a gear efficiency factor of one of the gears (The efficiency of one gear can only be estimated realative to the other gear).

The 14 model parameters are estimated by maximum likelihood.

	estimate	sd
growthrate	0.40	0.01
(Intercept)	-3.17	0.36
slope	-0.06	0.01
logscale1	-4.56	0.17
transf.AR1(time)	1.46	0.09
logGMRF1(gf)	-5.65	0.20
transf.AR1(size)	2.27	0.03
logscale2	0.31	0.10
logscale3	0.75	0.06
logscaleOSK	2.69	0.36
L50GOV	9.03	0.44
L50OSKAR	20.79	0.67
SRGOV	1.61	0.22
SROSKAR	2.95	0.26

Table 1: The 14 model parameters. The logscale (1-3) parameters are (indirectly) the log variances occurring in process 1-3. The parameter logscaleOSK denotes the log-efficiency of OSKAR gear relative to GOV for a large individual.

3 Model prediction

- Given these 14 parameters it is possible to make “the best guess” of the hidden processes 1-4.

- For instance the best guess of "Process 1" is given by $E(\text{Process } 1|\text{Data})$.

Model predictions are made on a size, space, time grid of dimensions

	number	stepsize
size grid	120	1 cm
spatial grid	457	14 km
time grid	156	1 week

Table 2: Discretization in size, space and time.

Year	Gear	1	2	3	4	5	6	7	8	9	10	11	12
2008	GOV	30	38	0	0	0	0	1	26	43	0	0	0
	OSKAR	0	0	0	0	0	19	39	0	0	0	0	0
2009	GOV	37	31	0	0	0	0	1	35	29	0	0	0
	OSKAR	0	0	0	0	0	0	0	0	0	0	0	0
2010	GOV	14	49	0	0	0	0	5	33	22	0	0	0
	OSKAR	0	58	0	0	60	0	0	0	0	59	0	0

Table 3: Yearly and monthly haul allocation for OSKAR and GOV.

3.1 Results (Prediction Process 1)

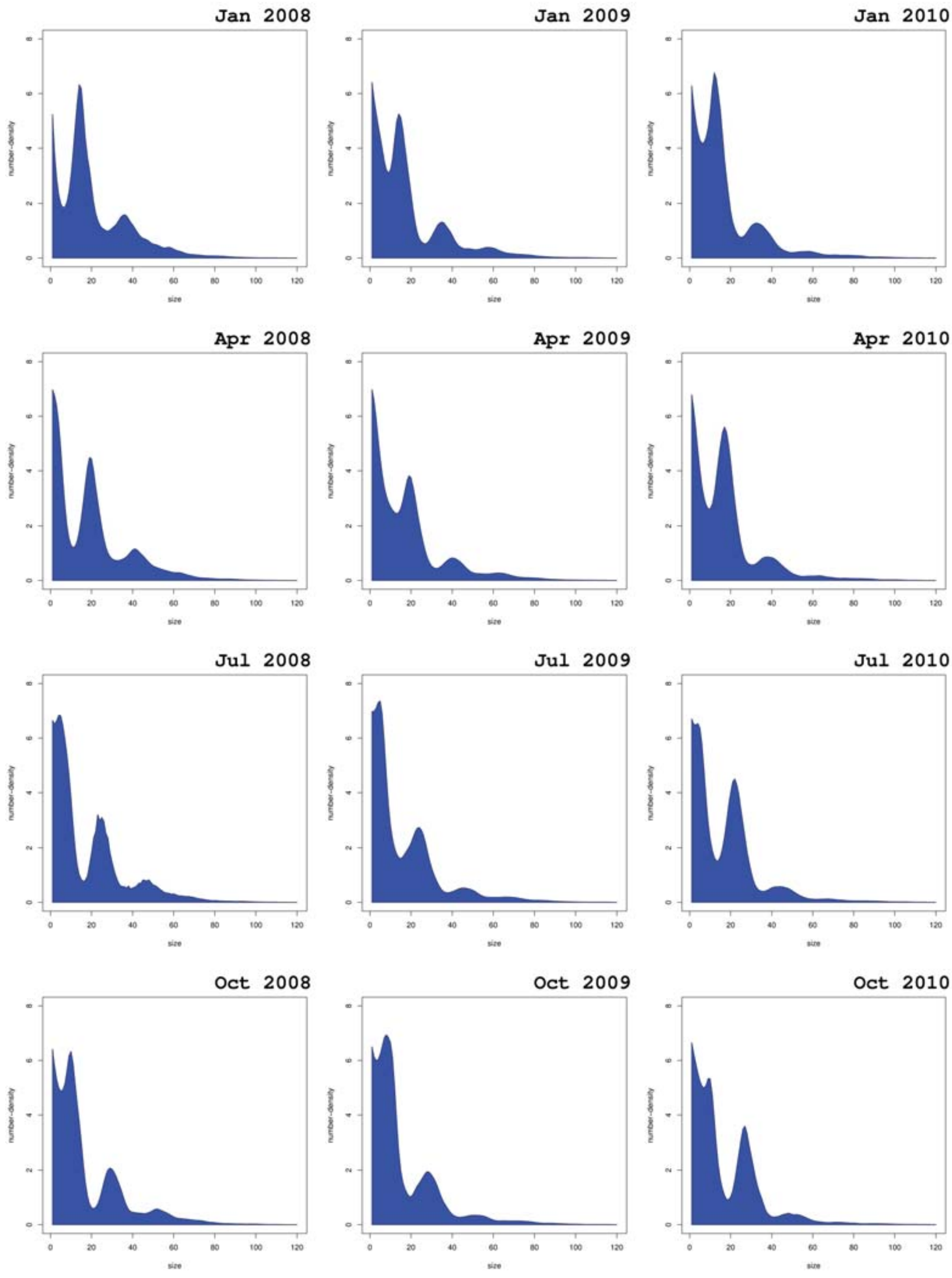


Figure 3: Cod: Prediction of the size spectrum (Process 1) the first week of each quarter from jan 2008 to dec 2010.

3.2 Results (Prediction Process 1+2 versus 1+2+4)

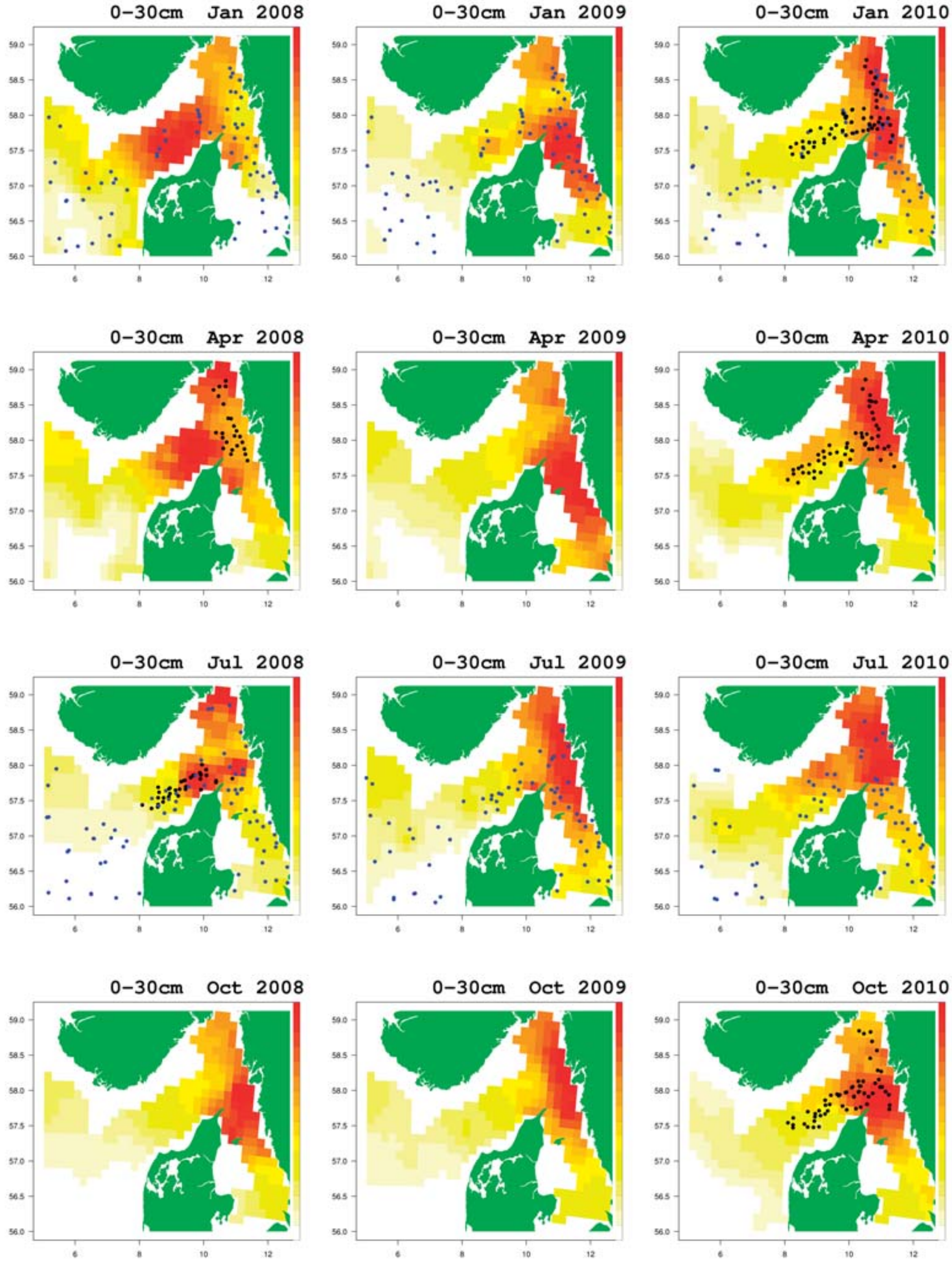


Figure 4: Prediction of the spatial distribution of size interval 0-30 cm (Process 1+2 integrated over the size interval 0-30 cm). Haul positions of any quarter-year combination are marked with black points (OSKAR) and blue points (GOV). Note that haul times are shown by quarter which can be misleading sometimes: for instance the hauls of Q2 2008 titled "Apr 2008" are taken in june and are therefore closer to the next display "Jul 2008". Example of color interpretation: The red color occupies roughly 20% of the color legend. This means that the red color on the color map highlights the smallest area containing 20% of the population.

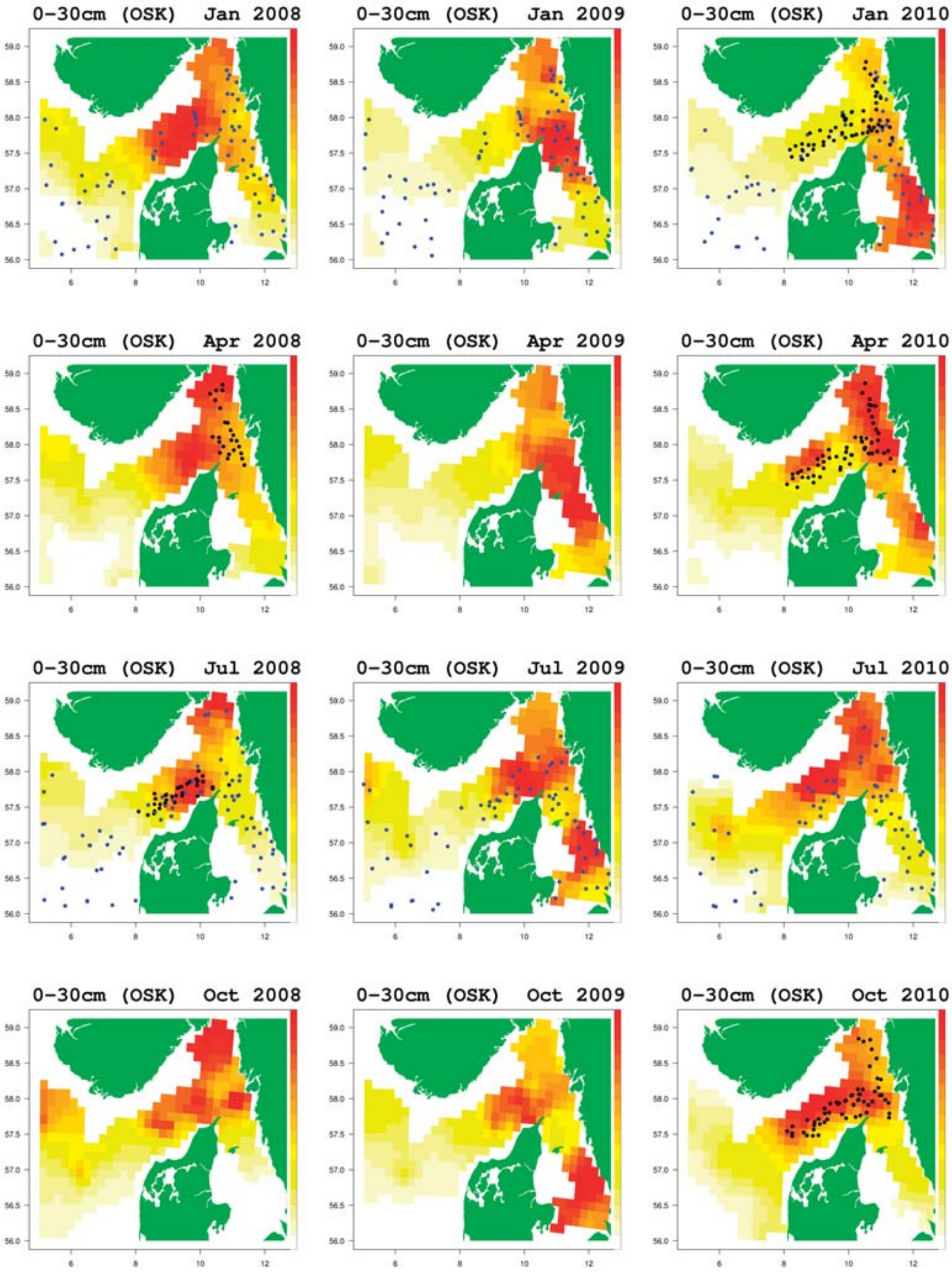


Figure 5: Prediction of the spatial distribution of size interval 0-30 cm as it would be seen through the OSKAR gear selection (Process 1+2+4 integrated over the size interval 0-30 cm).

3.3 Results (Prediction Process 1+2)

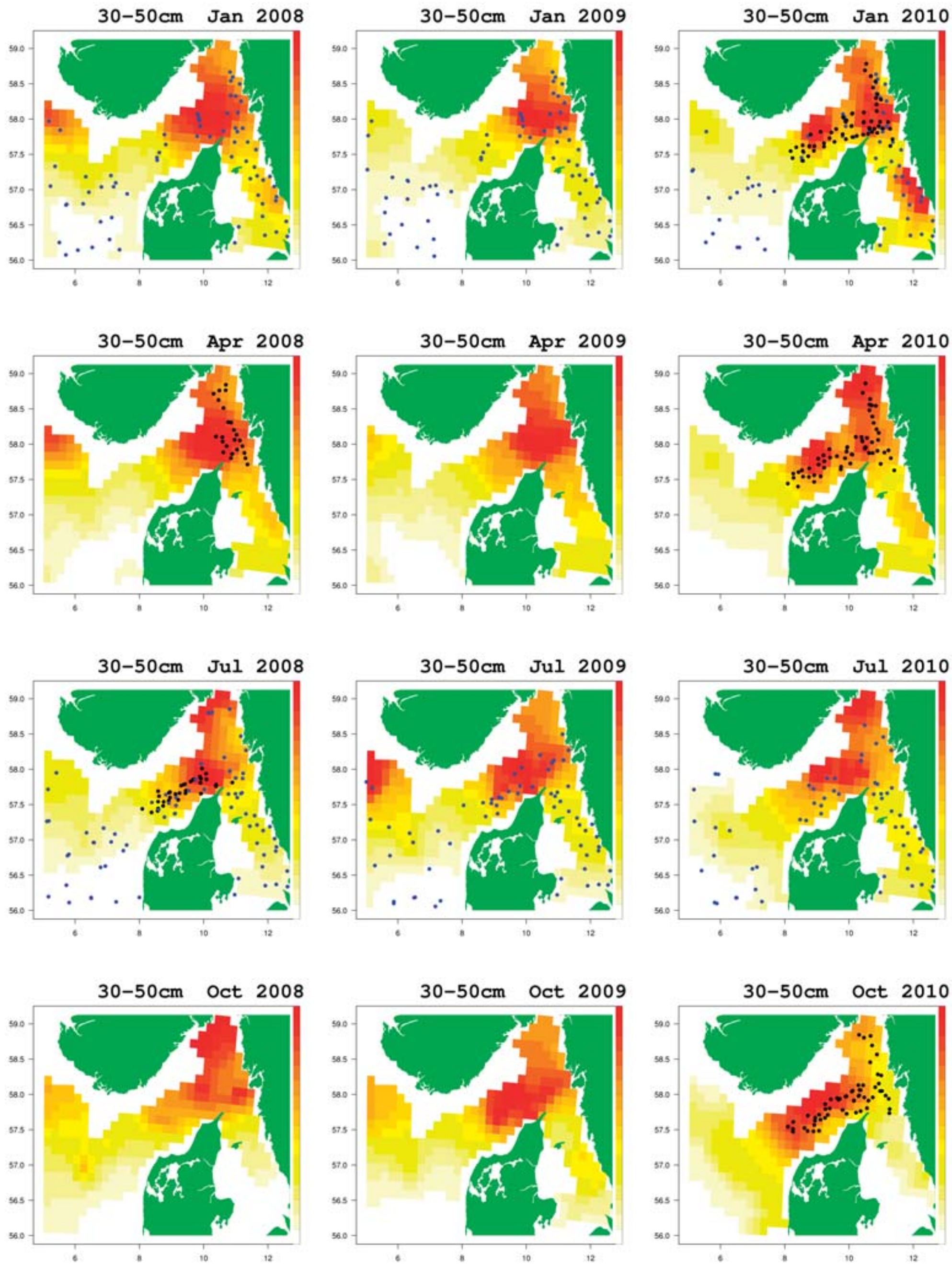


Figure 6: Prediction of the spatial distribution of size interval 30-50 cm (Process 1+2 integrated over the size interval 30-50 cm).

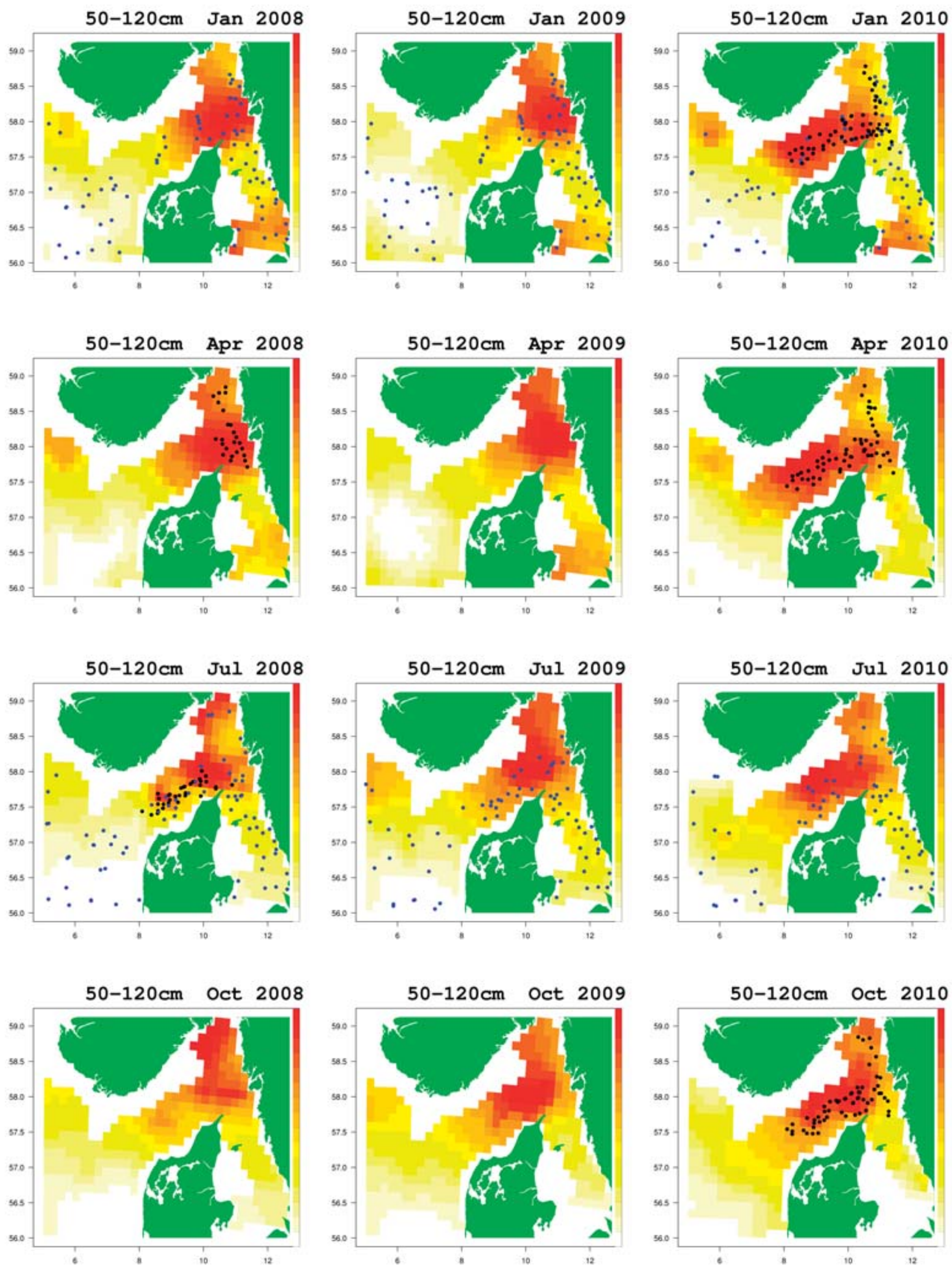


Figure 7: Prediction of the spatial distribution of size interval 50-120 cm (Process 1+2 integrated over the size interval 50-120 cm).

3.4 Results (Prediction by-catch-ratio)

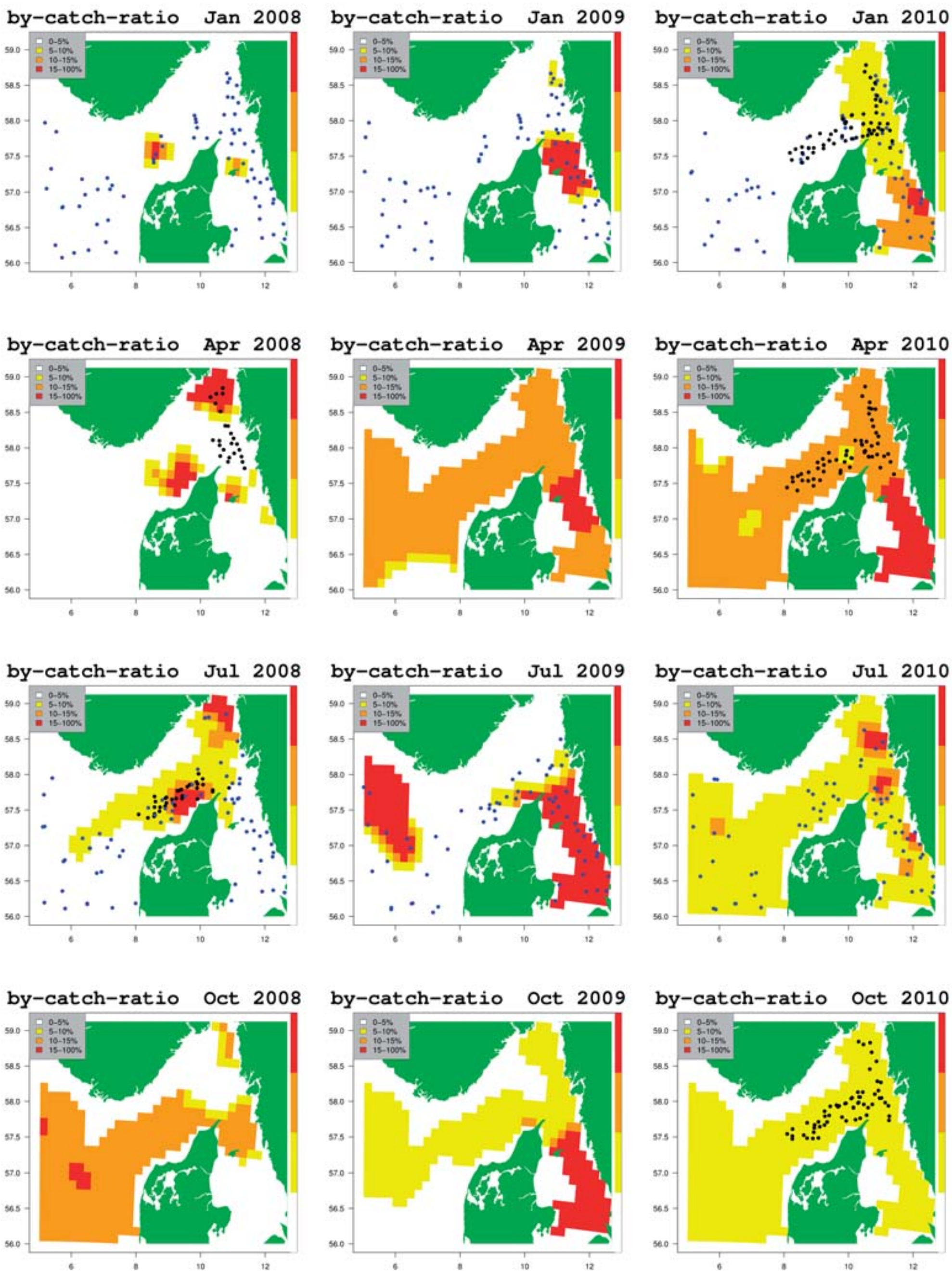


Figure 8: Prediction of the spatial distribution of biomass by-catch-ratio (seen through OSKAR gear selection) defined as the biomass in size interval 0-30cm divided by total biomass. Formally, biomasses are found by integrating Process 1+2+4, weighted by the fish-length raised to the third power, over the desired size range. Interpretation: If a large number of hauls are taken outside the red area then the aggregated catch will have a by-catch-ratio smaller than 15%.

3.5 Results (Prediction risk >15% by-catch)

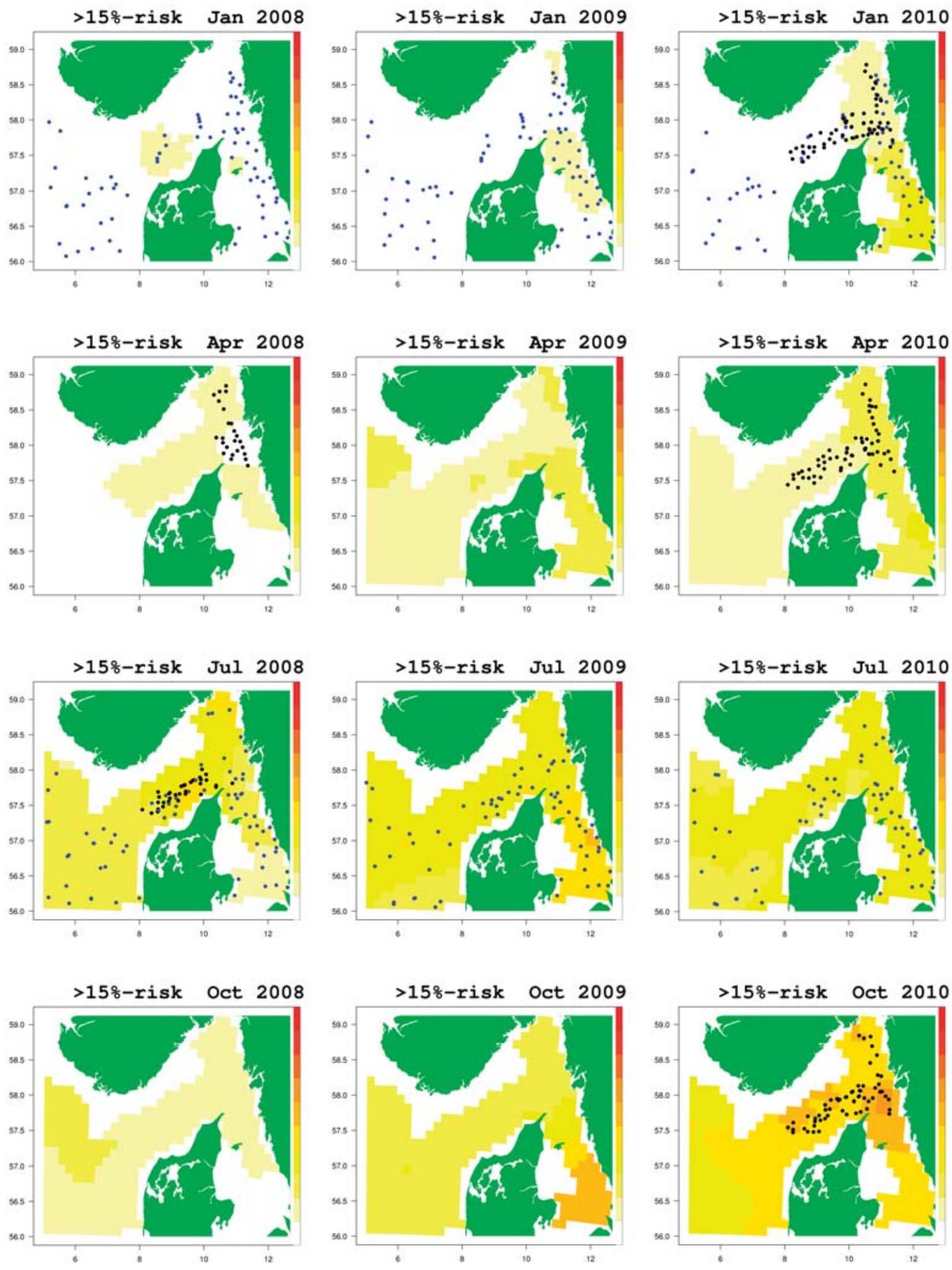


Figure 9: Spatial prediction of the risk (probability) of catching more than 15% by-catch with the OSKAR gear when accounting for the small scale variations. Interpretation: Single haul version of Fig. 8. Shows very little contrast because of the dominating small-scale variability.

4 Including REX data

The purpose of the following study was to demonstrate that the hauls from the REX survey could easily be included in the analysis. This is a straight forward extension requiring just three more gear selection parameters: $L50$, SR and a gear efficiency parameter. Furthermore, the effect of depth and hour was included in the model.

	estimate	sd	P(Chi^2>|x|)
(Intercept)	-0.67	1.36	0.62
I(numsize - 30)	-0.06	0.01	0.00
GearOSKAR	2.91	0.35	0.00
GearREX	4.95	0.48	0.00
poly(Depth, 2)1	78.53	17.27	0.00
poly(Depth, 2)2	-86.24	16.12	0.00
I(log(DoorSpread))	-0.16	0.07	0.03
Hour4	-1.72	1.39	0.22
Hour5	-2.12	1.36	0.12
Hour6	-1.88	1.36	0.17
Hour7	-1.84	1.35	0.17
Hour8	-1.63	1.37	0.23
Hour9	-1.93	1.36	0.16
Hour10	-1.83	1.36	0.18
Hour11	-1.70	1.36	0.21
Hour12	-1.95	1.36	0.15
Hour13	-1.85	1.36	0.17
Hour14	-1.79	1.36	0.19
Hour15	-2.02	1.36	0.14
Hour16	-1.91	1.36	0.16
Hour17	-1.91	1.38	0.17
Hour18	-2.15	1.38	0.12
Hour19	-1.63	1.39	0.24
Hour20	-2.70	1.43	0.06
Hour21	-1.27	1.48	0.39
logscale2	0.77	0.05	0.00
transf.AR1(size)	2.27	0.02	0.00
logscale	0.12	0.10	0.24
transf.AR1(time)	1.38	0.08	0.00
logGMRF1(gf)	-5.74	0.18	0.00
logscale3	-4.95	0.18	0.00
p	0.39	0.01	0.00
L50GOV	8.92	0.32	0.00
L50OSKAR	20.90	0.42	0.00
L50REX	27.75		
SRGOV	1.56	0.15	0.00
SROSKAR	2.93	0.17	0.00
SRREX	3.62		

Table 4: Parameter estimates in the extended model with GOV, OSKAR and REX data applied simultaneously accounting for the depth effect and the hour effect. The hour effect is not significant because the p-values 3rd column are greater than 5%. However, the effect of depth is significant because the p-values are smaller than 5%.

4.1 Including REX data (continued)

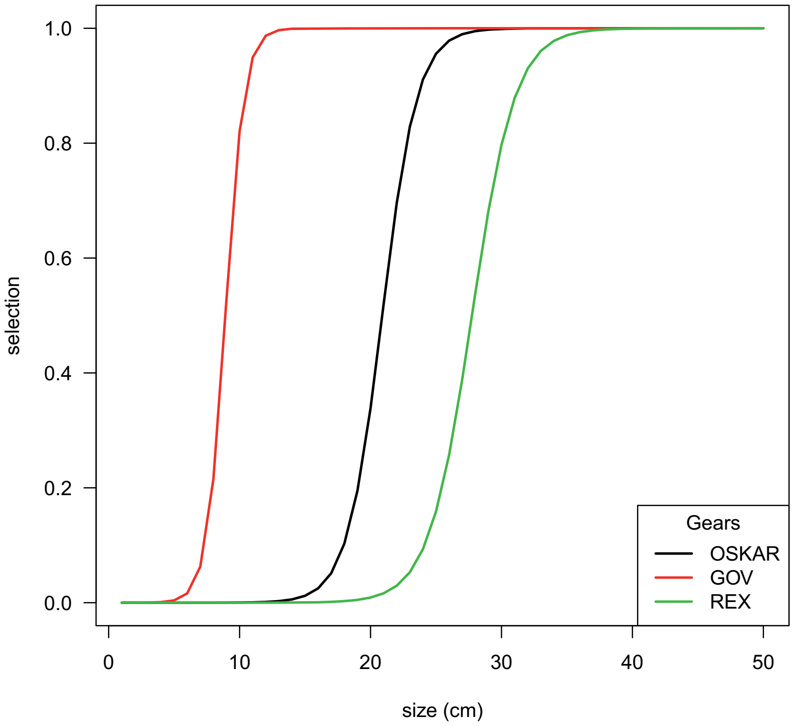


Figure 10: Estimated gear selection curves of GOV (red), OSKAR (black) and REX (green).

4.2 Depth effect

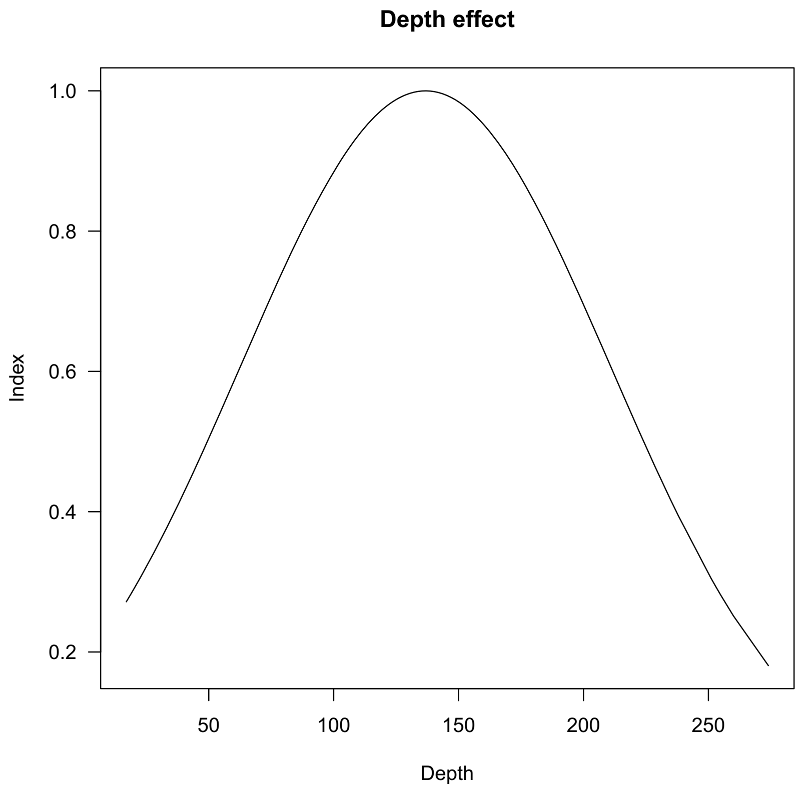


Figure 11: Estimated depth effect as a second order polynomial of depth (A gaussian shaped effect on natural scale).

5 Haddock

The model was also applied on the haddock data:

- Same grid in space and time.
- Both IBTS and Oskar data included.
- Size interval 0-60cm is considered.
- Two groups: above/below 30cm.

5.1 Parameter estimates (Haddock)

	estimate	sd
growthrate	0.29	0.01
(Intercept)	-3.88	0.46
slope	-0.12	0.02
logscale1	-3.35	0.14
transf.AR1(time)	1.37	0.12
logGMRF1(gf)	-4.19	0.28
transf.AR1(size)	2.00	0.02
logscale2	1.54	0.12
logscale3	1.71	0.06
logscaleOSK	2.93	0.47
L50GOV	10.90	0.52
L50OSKAR	17.73	0.38
SRGOV	1.66	0.17
SROSKAR	1.65	0.12

Table 5: Parameter estimates for haddock.

5.2 Results: Gear selectivity

$$\text{sel}(s) = \frac{1}{1 + 3^{-\frac{2}{SR}(s - l_{50})}}$$

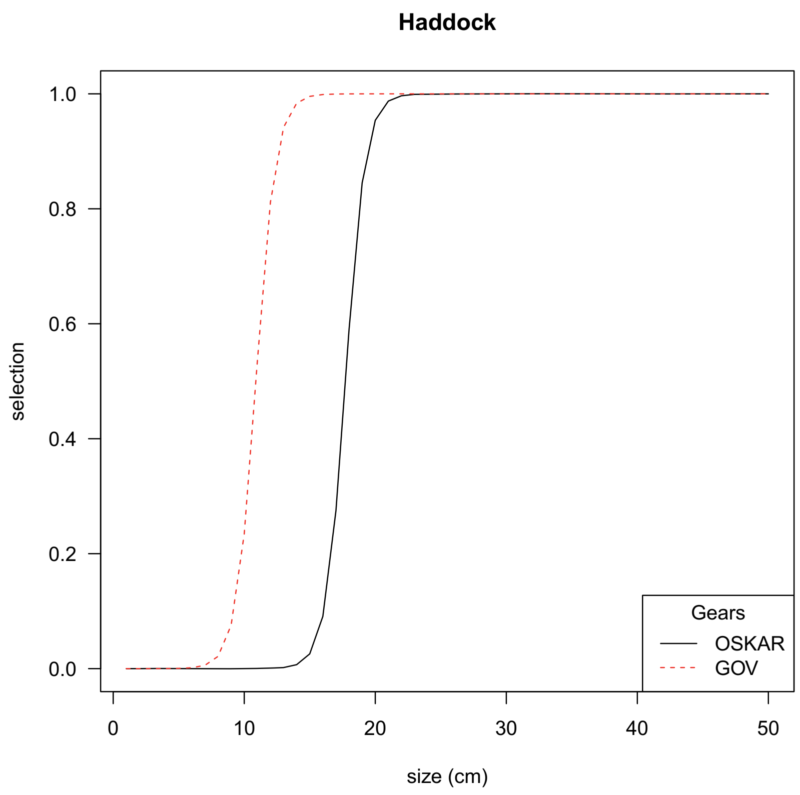


Figure 12: Haddock: Estimated gear selection curves of GOV (red) and OSKAR (black).

5.3 Results (Prediction Process 1)

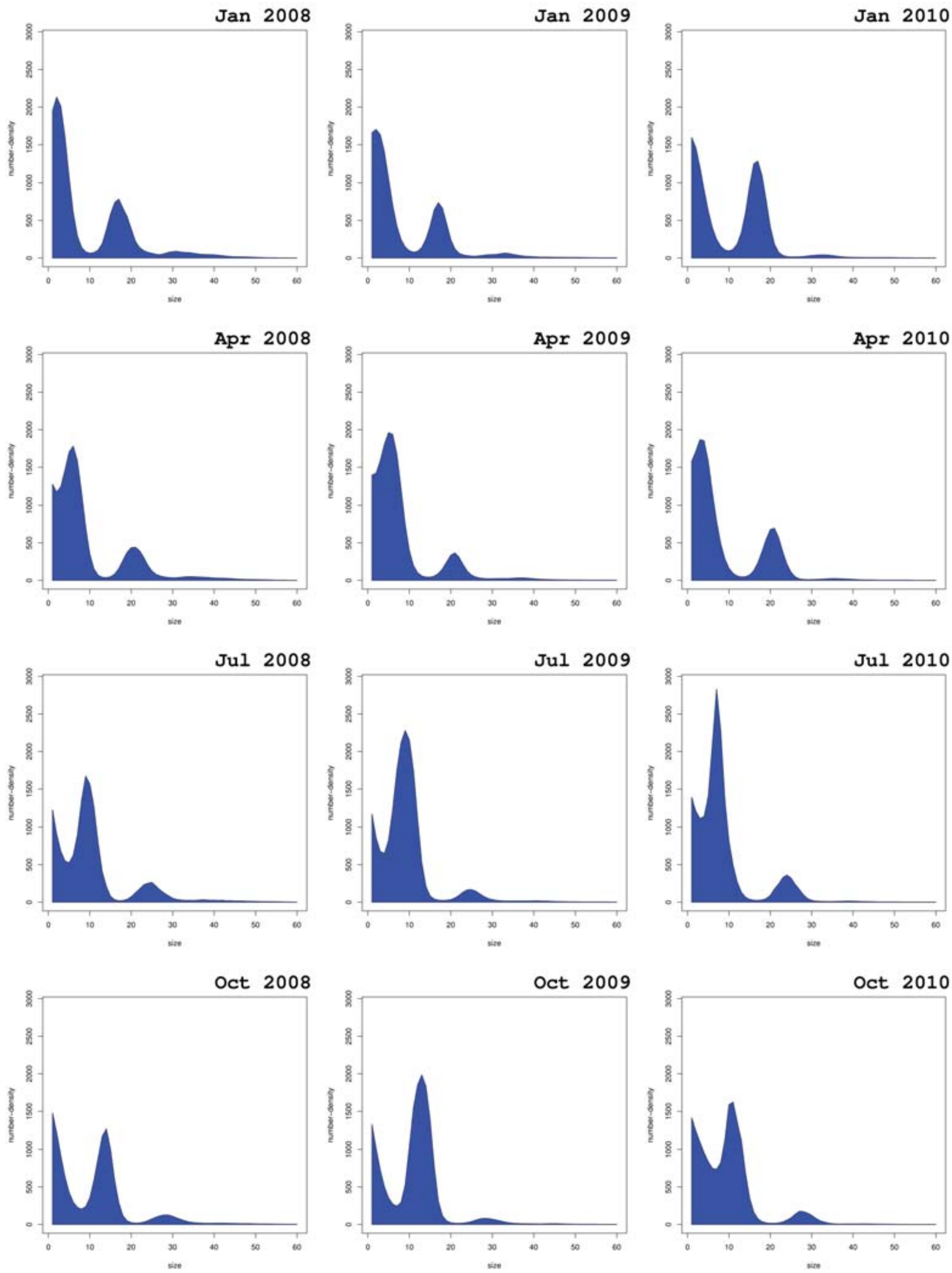


Figure 13: Prediction of the haddock size spectrum (Process 1) the first week of each quarter from jan 2008 to dec 2010.

5.4 Results (Prediction Process 1+2 versus 1+2+4)

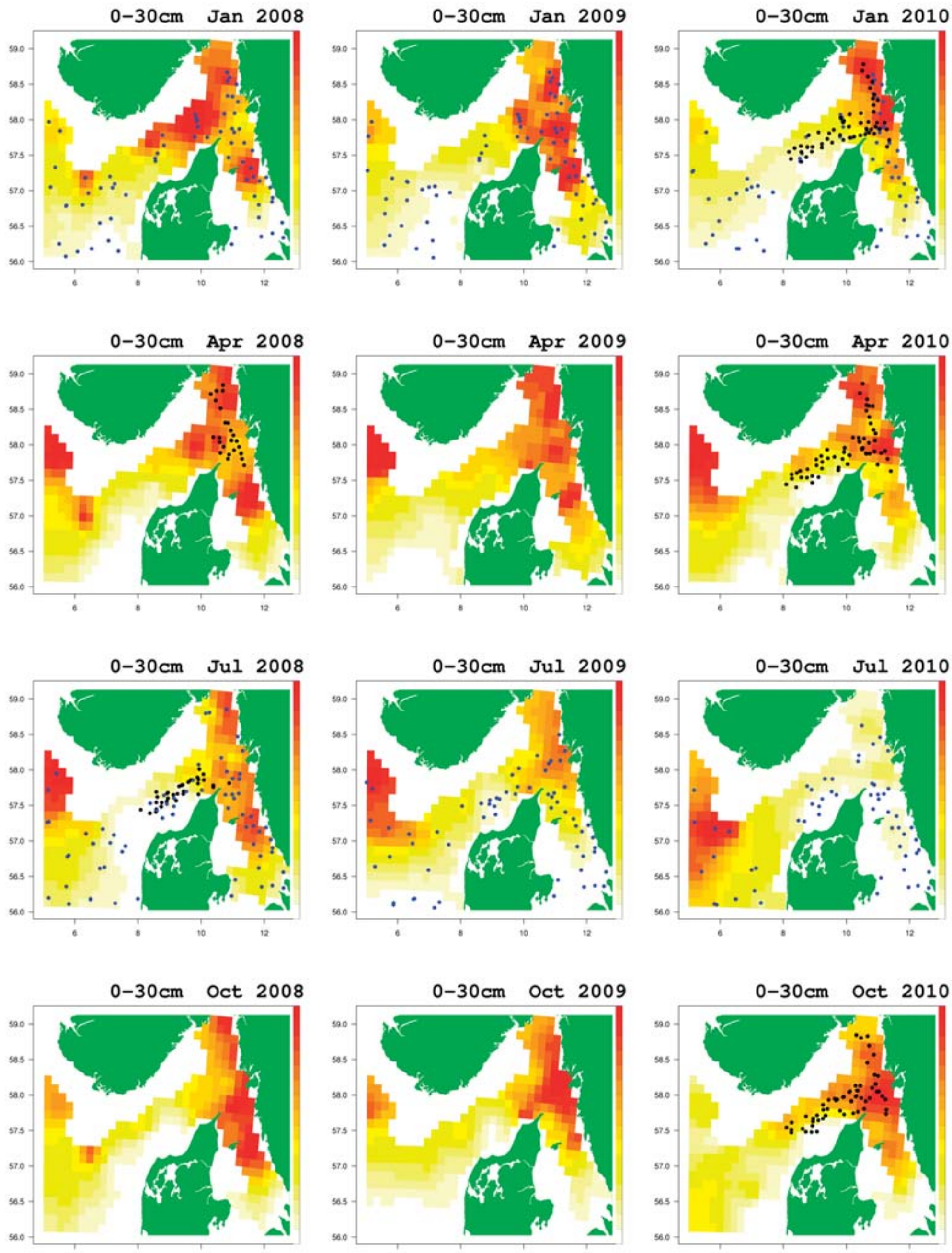


Figure 14: Haddock: Prediction of the spatial distribution of size interval 0-30 cm (Process 1+2 integrated over the size interval 0-30 cm).

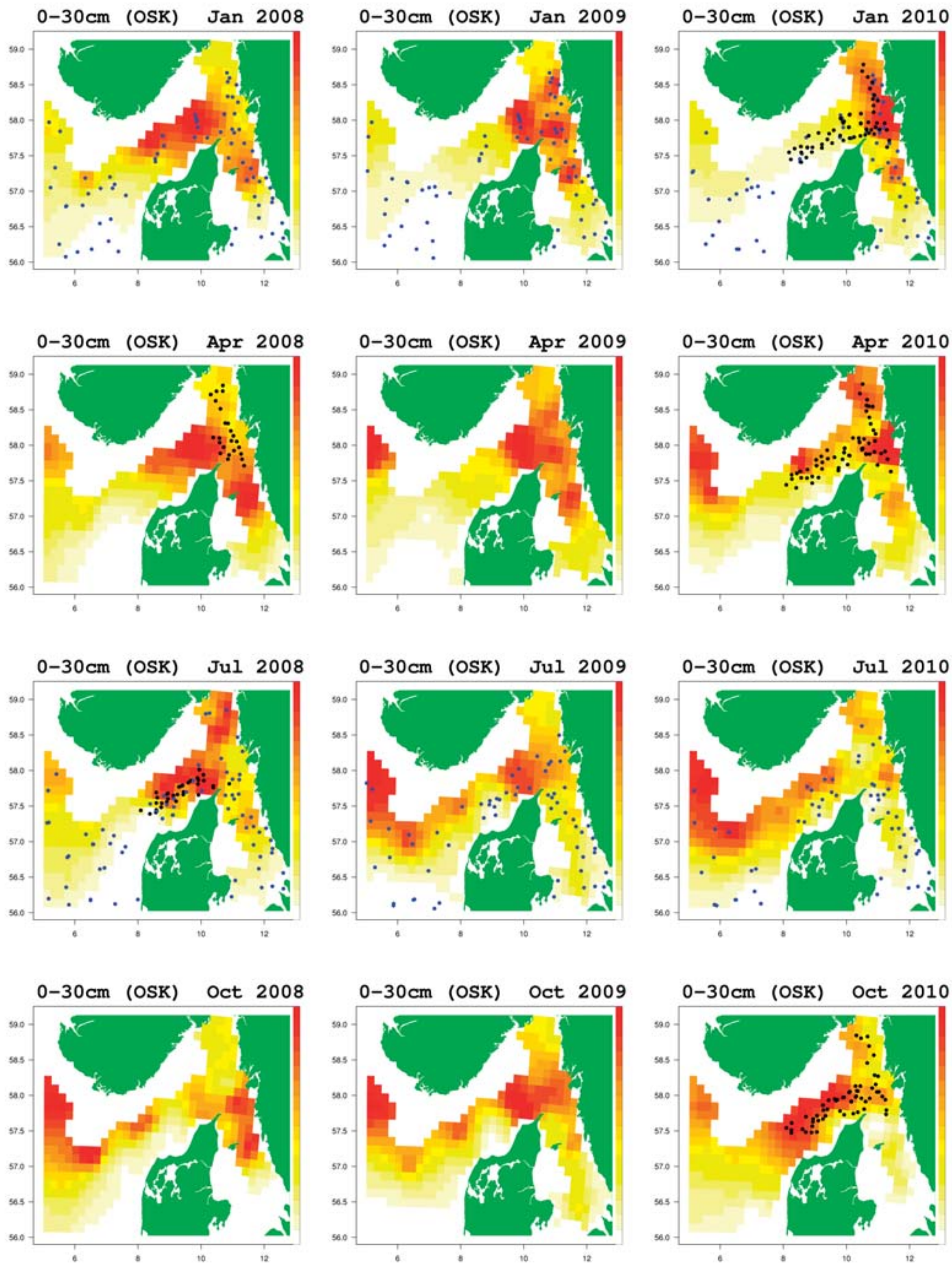


Figure 15: Haddock: Prediction of the spatial distribution of size interval 0-30 cm as it would be seen through the OSKAR gear selection (Process 1+2+4 integrated over the size interval 0-30 cm).

5.5 Results (Prediction Process 1+2)

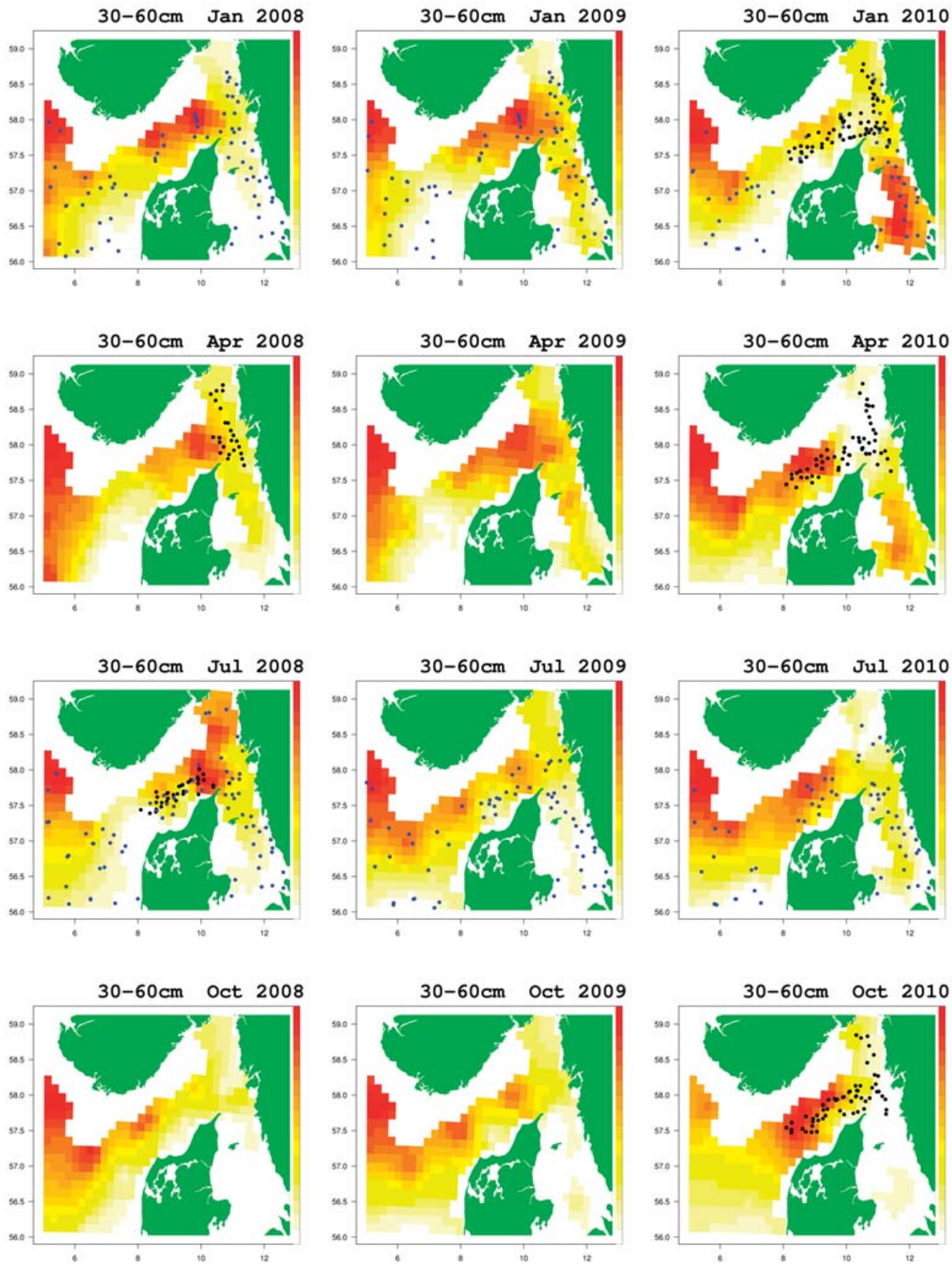


Figure 16: Haddock: Prediction of the spatial distribution of size interval 30-60 cm (Process 1+2 integrated over the size interval 30-60 cm).

5.6 Results (Prediction risk>15% by-catch)

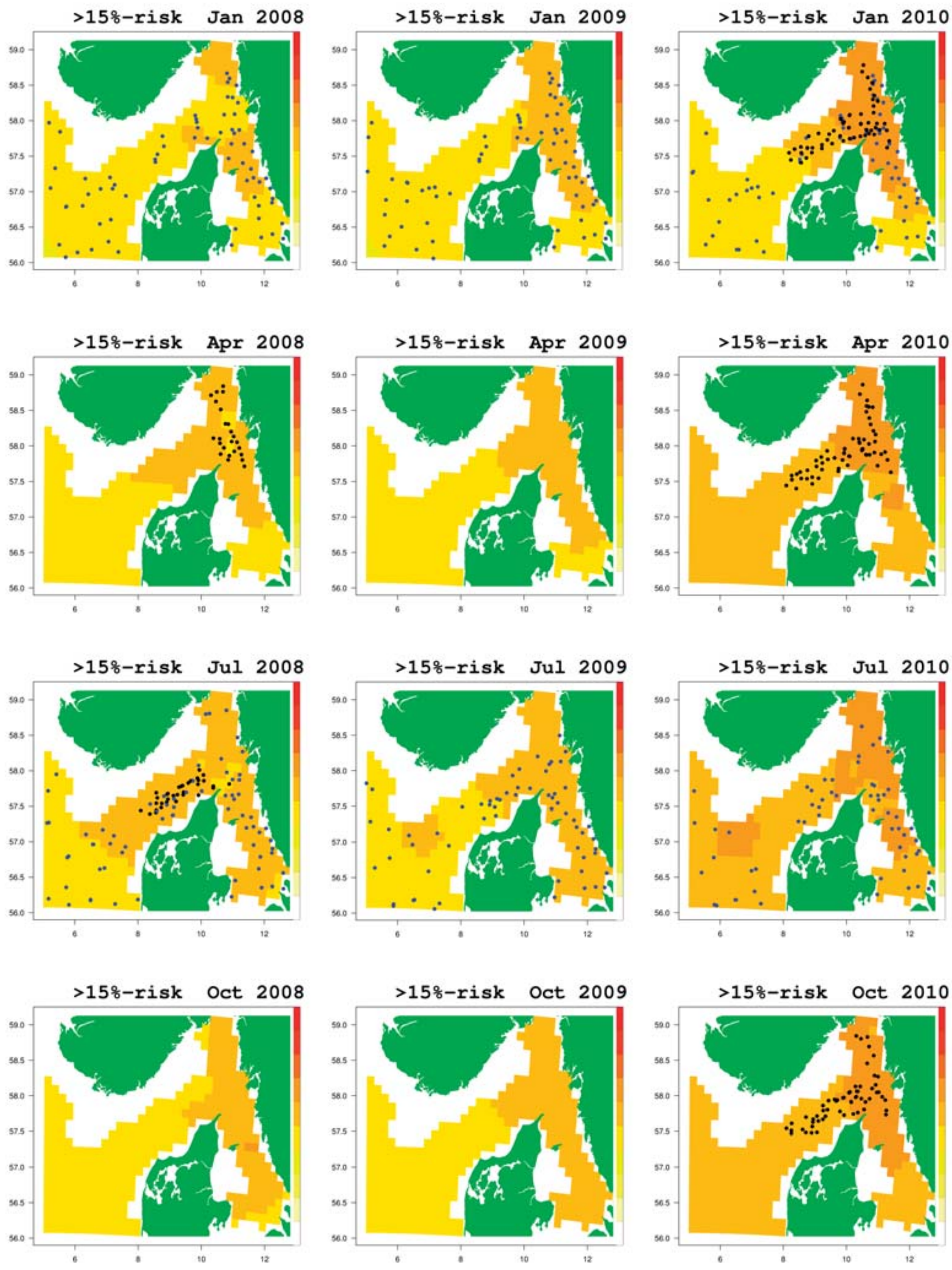


Figure 17: Haddock: Spatial prediction of the risk (probability) of catching more than 30% by-catch with the OSKAR gear when accounting for the small scale variations.

6 IBTS alone

- Model is run without Oskar data.
- Entire analysis is repeated: (1) parameter estimation. (2) prediction.
- Some of the prediction maps requires oskar-selection. We use the “old” estimate.

6.1 Results (Prediction Process 1)

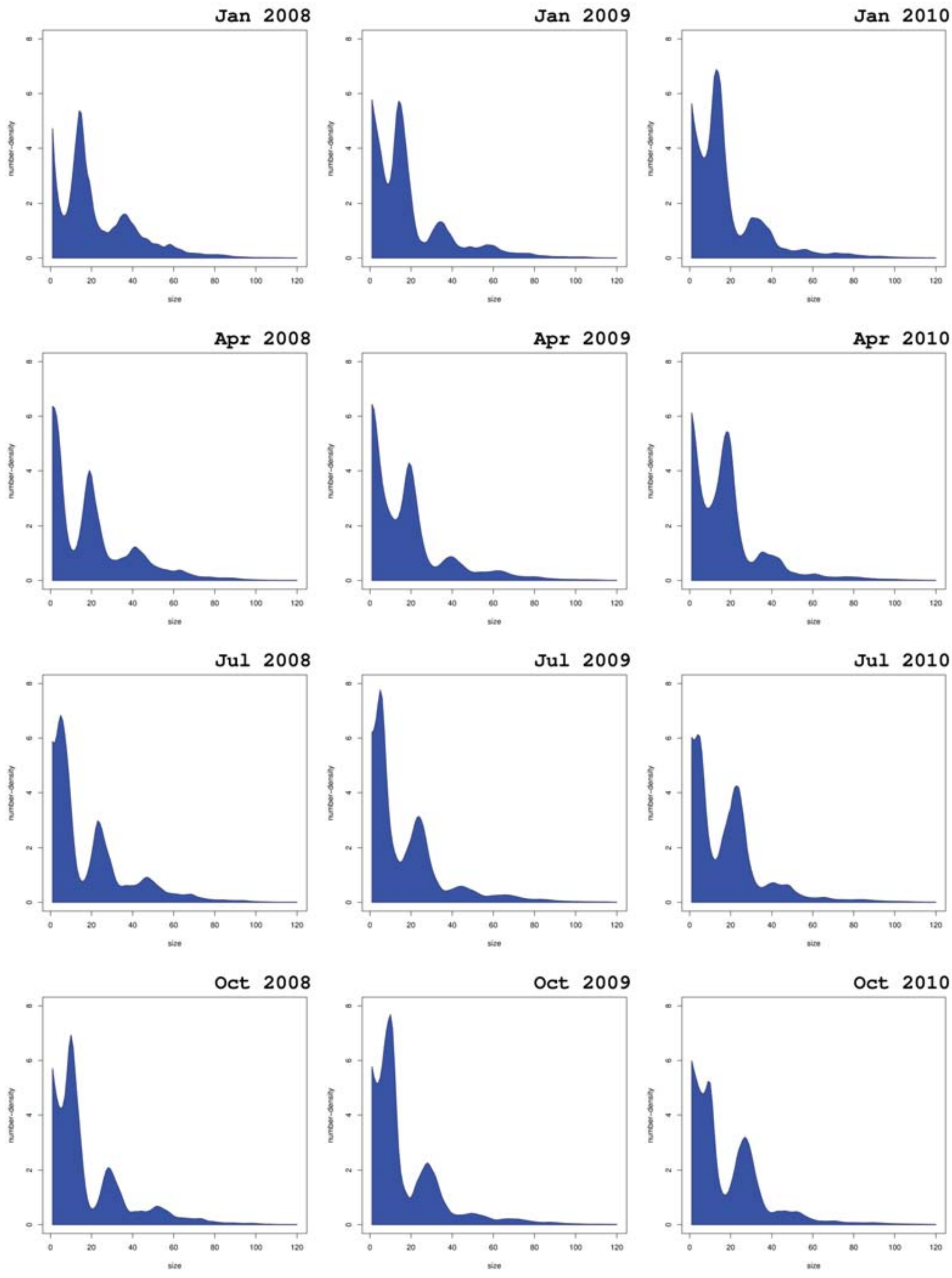


Figure 18: Cod: Prediction of the size spectrum (Process 1) the first week of each quarter from jan 2008 to dec 2010 based only on IBTS data.

6.2 Results (Prediction Process 1+2 versus 1+2+4)

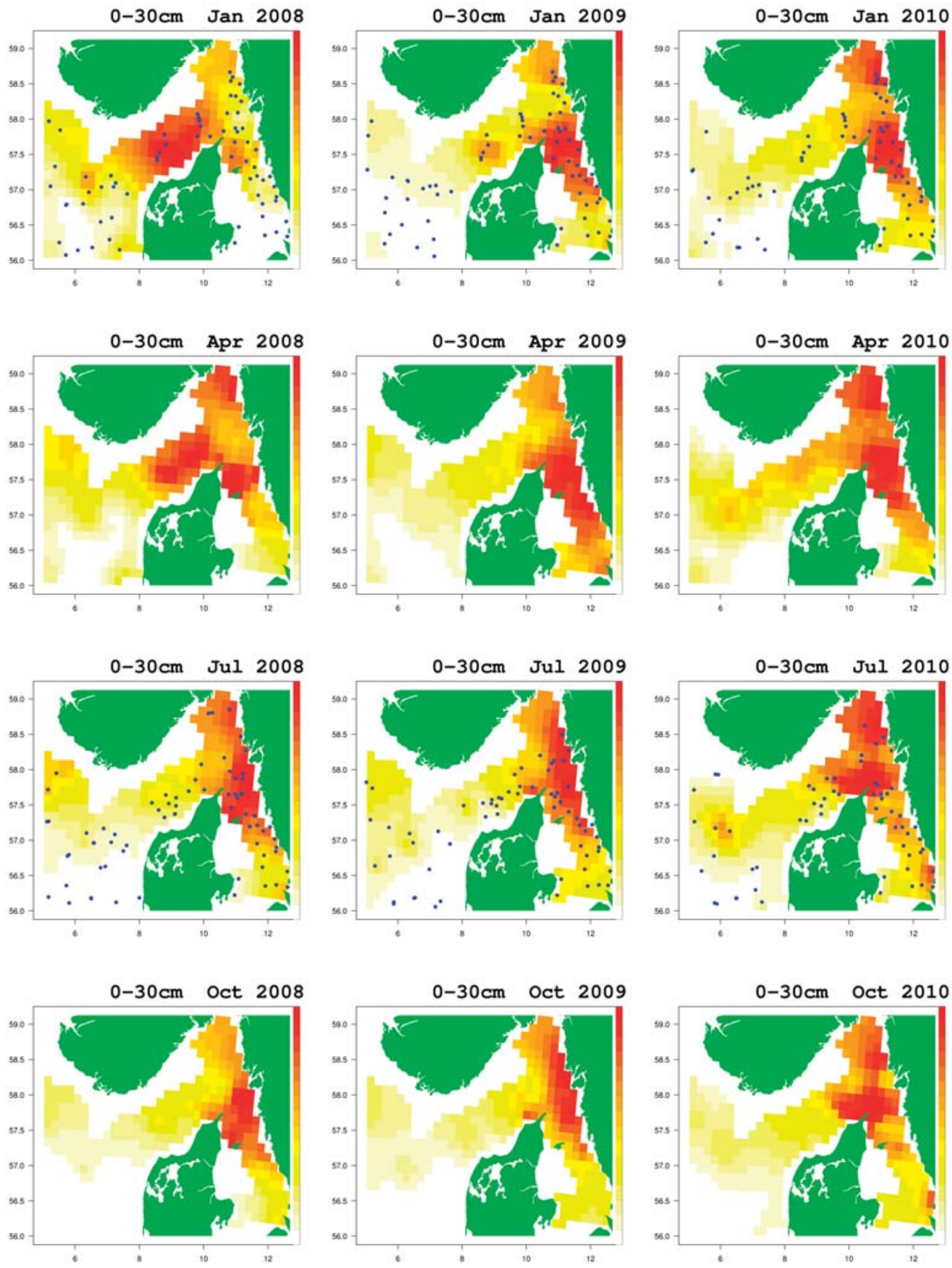


Figure 19: Cod: Prediction of the spatial distribution of size interval 0-30 cm (Process 1+2 integrated over the size interval 0-30 cm) based only on IBTS data.

6.3 Results (Prediction Process 1+2)

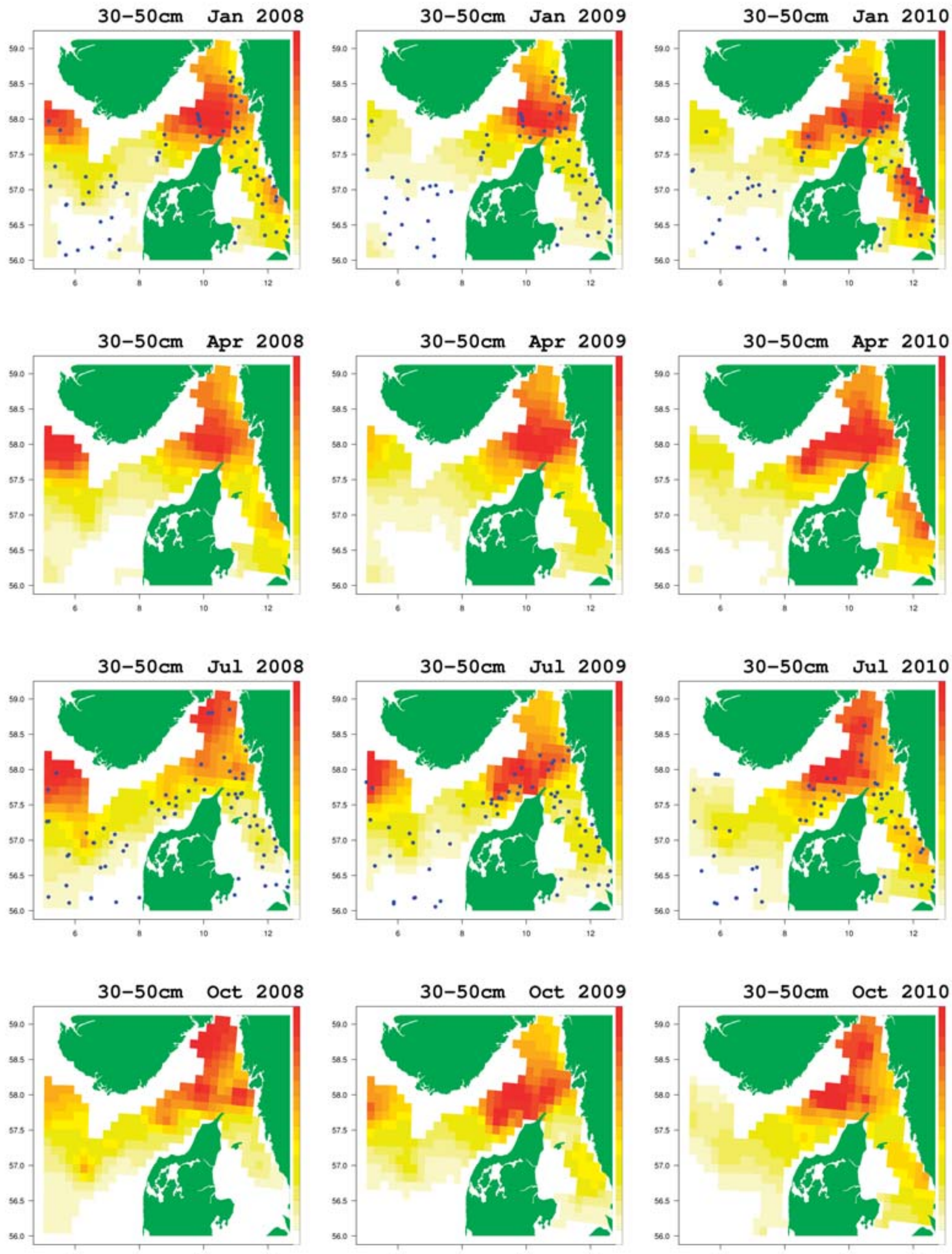


Figure 20: Cod: Prediction of the spatial distribution of size interval 30-50 cm (Process 1+2 integrated over the size interval 30-50 cm) based only on IBTS data.

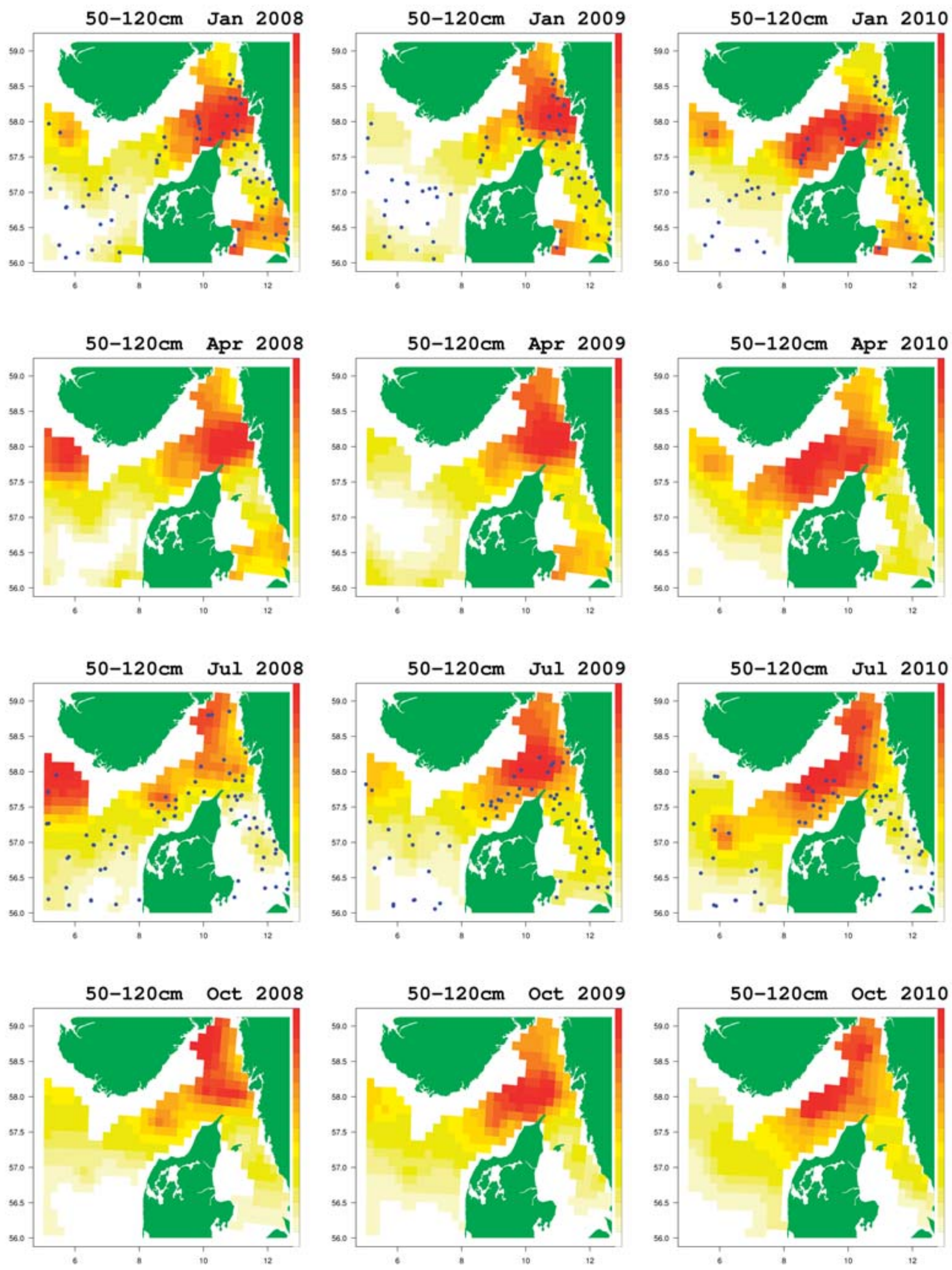


Figure 21: Cod: Prediction of the spatial distribution of size interval 50-120 cm (Process 1+2 integrated over the size interval 50-120 cm) based only on IBTS data.

6.4 Results (Prediction risk>15% by-catch)

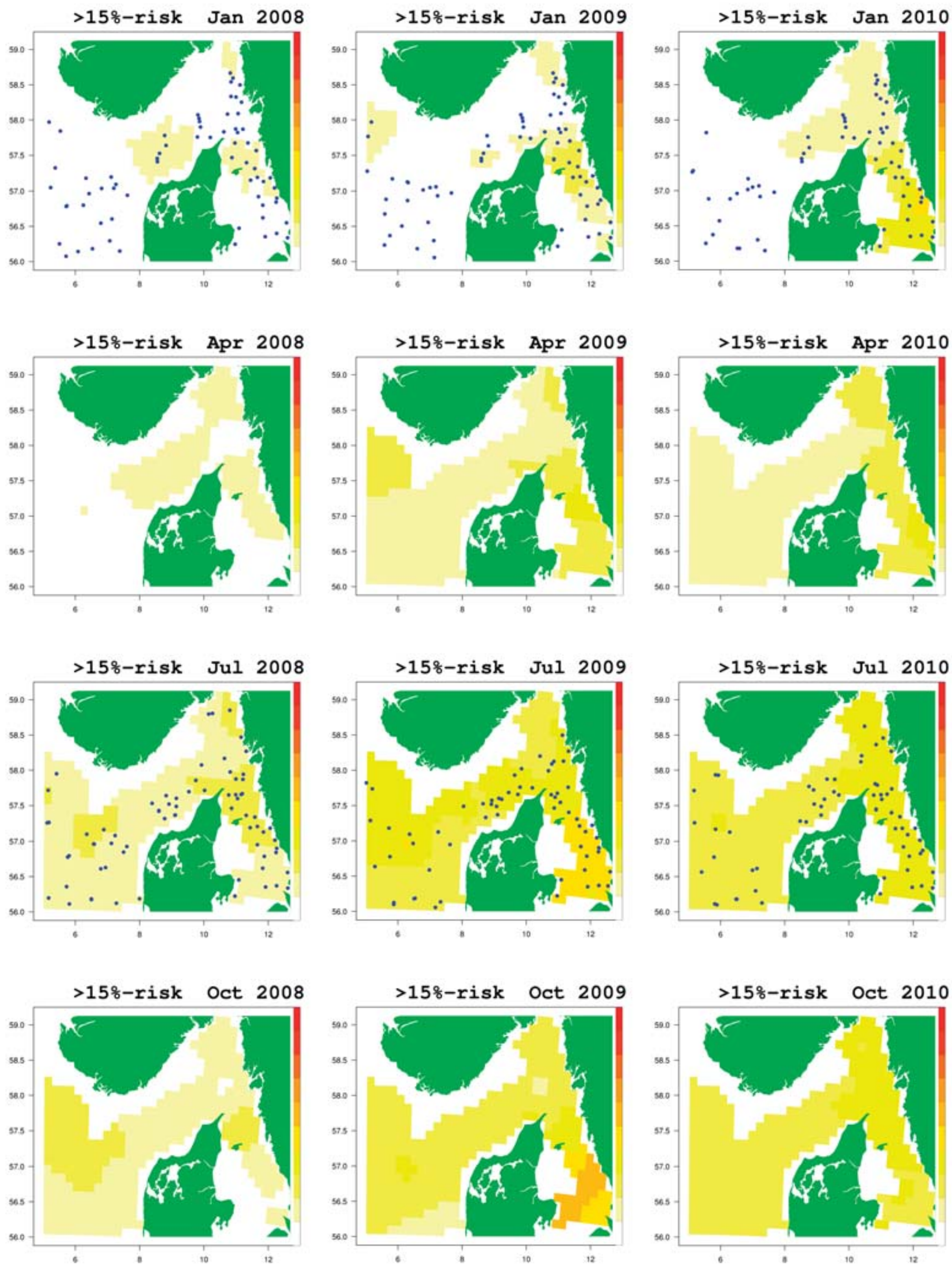


Figure 22: Cod: Spatial prediction of the risk (probability) of catching more than 15% by-catch with the OSKAR gear when accounting for the small scale variations based only on IBTS data.

7 Discussion

It has been demonstrated how a hidden gaussian Markov random field model can deal with many different data sources consistently. The essential assumption is that the trawl samples are in fact the same physical processes differing only by the relative size selection and the gear efficiency. The underlying small scale variablity and large scale fields are the same. This critical assumption has to some degree been verified by the fact that the parameter estimates are fairly unaffected when the data material is extended step by step. Once this consistency check has passed, it makes sense to ask whether the predicted surfaces appear to change when extending the GOV data with the OSKAR data. Before making comparisons lets emphasize som general rules. Adding additional data will always *increase* the precision of the estimated surfaces provided that the model is correct. If a visible change is detected when adding extra data there can be two major explanations: 1. The change is caused by improved precision. 2. The model is inconsistent. The formal way to reveal a model inconsistency would be to check whether the new estimate (with both datasets) is outside the confidence limits of the old estimate (with only one dataset).

A less formal approach is to compare estimated images by eye. If a visible difference is detected then the spatio-temporal overlap between the data sources should be assessed. A small overlap would indicate improved precision. A high overlap would seem to indicate a model inconsistency. With this in mind lets make the comparison:

- Overall, the size distributions are quite unaffected (Compare Fig 3 with Fig 18).
- The size group 0-30cm are generally very equal with a some visible difference July 2008 and April 2010 (Compare Fig 4 with 19).
- The size group 30-50cm show some differences for 3rd quarter 2008 and 4th quarter 2010 (Compare Fig 6 with 20).
- The size group 50-120cm are quite equal (Compare Fig 7 with 21).
- The by-catch-risk maps show only few differences (Compare Fig 9 with Fig 22).

The described differences all tend to occur arround the months June-July 2008 and May 2010. These periods are characterized by having no temporal overlap between OSKAR and GOV hauls (Table 3). The difference therefore likely reflects an increased precision caused by the improved temporal coverage of the OSKAR survey. Months for which both OSKAR and GOV hauls are available tend to show remarkably equal estimated images.

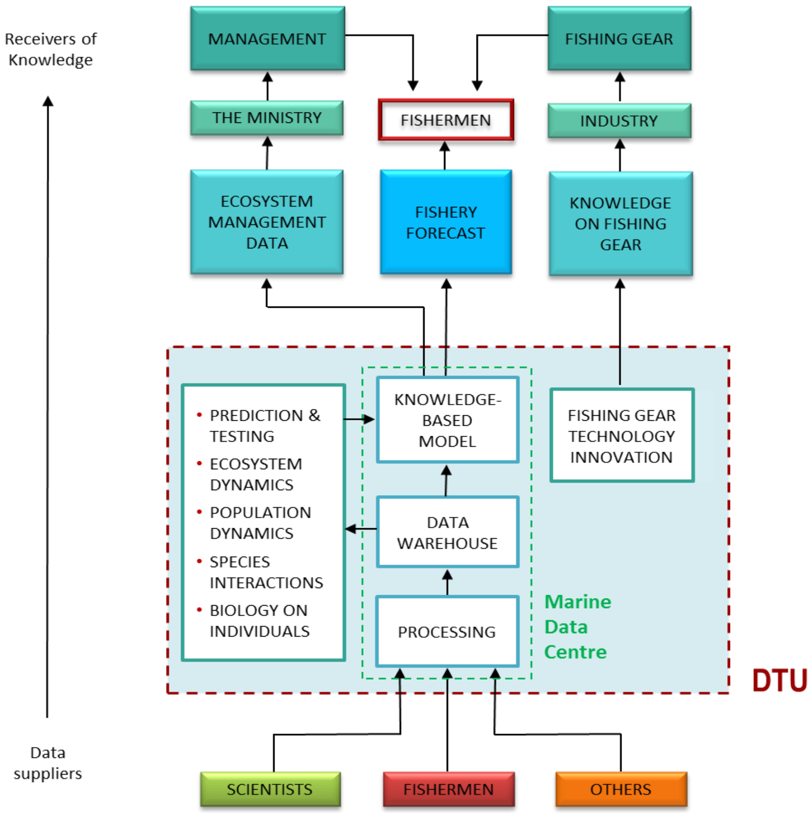
The perhaps most important result of the present study is the effect of the dominating small scale variability. The consequence is very clear when comparing the expected by-catch map (Fig. 8) with the by-catch *risk* map (Fig. 9.). The first map (Fig. 8) indicates that it is possible to control the total by-catch *of a fleet* by allocating hauls in a spatially intelligent way: if the red areas are avoided then the aggegation of all hauls will have a by-catch smaller than 15%. On contrary, Fig. 9 shows that it is impossible to obtain similar control for the *single haul*: No matter where a haul is taken there is always a significant risk of getting an illegal catch, unless the haul is taken at specific seasons.

Work package G

(Project idea)

Integrated fishery and management in the marine ecosystem

by Bjarne Stage



Introduction

The intensity and complexity of human activities in the marine environment is steadily increasing. To protect the natural environment and manage these activities accordingly, the Habitat Directive [1], the Birds Directive [2], and the Marine Strategy Framework Directive [3] have been issued. A major challenge will be to combine the traditional approach to fisheries management with the ecosystem approach [4]. Other impending political initiatives are catch quota management and full documentation [5]. These directives and political initiatives will change fisheries and fisheries management substantially in the decade ahead. The purpose of this work package is to outline a range of opportunities for implementation of these initiatives by closer integration of fisheries and fisheries management.

Marine ecosystem management

Marine ecosystems are diverse, complex, and dynamic due to unpredictable natural variation from year to year. Ecosystem management depends on a socio-political system, which in itself is complex and dynamic. The concept for managing marine ecosystems can, therefore, be expected to change over time. Fisheries and fisheries management will have to adapt to this complex and dynamic environment. How to monitor, assess and manage fisheries must therefore be left open to evolve and improve over time. Future fisheries must be both ecologically as well as economically sustainable.

Compared to the present single species management, future management will require more data in order to assess the impact of fisheries on the ecosystem. Impact assessment will become an important tool to create access to fishing resources in areas that might otherwise become closed for fishing. Further data requirements will arise from the need to predict available fishing resources and optimize their exploitation under dynamic conditions. A major future challenge will be to provide these data at an acceptable cost.

Catch quota management

A byproduct of catch quota management will be catch composition reports that will be available without additional cost. The Oskar project has demonstrated that such data, combined with data from scientific surveys can be utilized by the GeoPop model to provide reliable information on the location of species and size group on small spatial and temporal scales. Due to the large amounts of data the precision of the model predictions will be high, and by combining data from fisheries and scientific surveys a common and consistent data frame is established. Although the initial approach to catch quota management is based on traditional fisheries management a future evolution towards an ecosystem based approach seems possible. Implementation of the catch quota system is anticipated to spur technological innovation in fishing gear and sensors, which will allow the fishermen to get the highest economical benefit of their quotas.

Sensor based fisheries

Echo sounders and fishing sonars have proven valuable sensors for locating and recognizing fish in pelagic fisheries. Further developments in technology that will allow precise identification of species as well as size composition are anticipated. A similar evolution is expected to occur in demersal fisheries with optical and acoustic sensors that will allow the catch process to be observed. Combining these technologies with sensors measuring current, turbidity, temperature, salinity, seabed flora and fauna and other parameters that influence the behaviour of target species will allow the accumulation of knowledge that can be used to optimize fisheries operations.

Scientific surveys

Although many standard scientific measurements can be performed by commercial fishermen as part of the fishing operation, there will still be a need for scientific surveys. This includes surveys that utilize non standard equipment, surveys in areas that are not targeted by commercial vessels and development of new survey concepts. Further, existing surveys should be continued in order not to disrupt very valuable time series.

Integrated fisheries and fisheries management in the marine ecosystem

New political initiatives, existing surveys and fishing operations can evolve by combination into integrated fisheries and fisheries management as illustrated in figure 1.

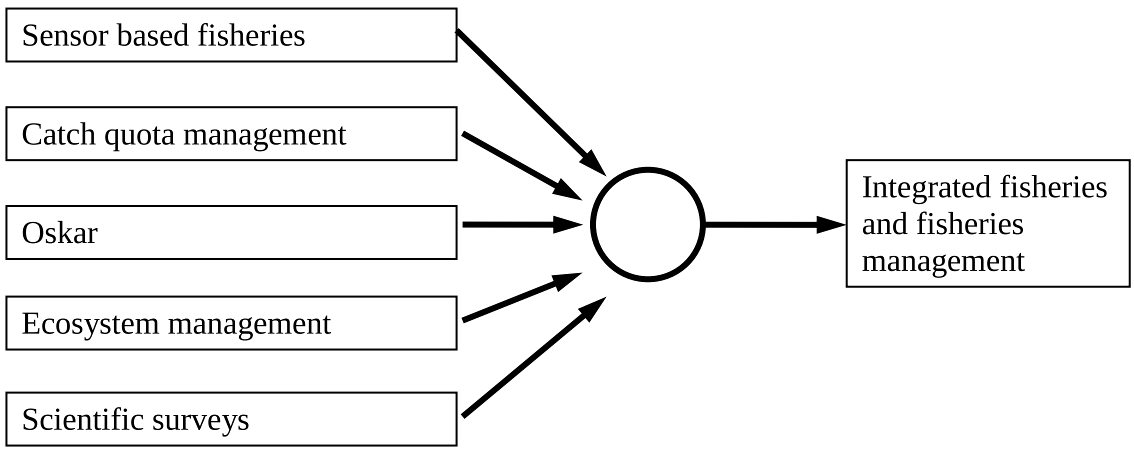


Figure 1. Evolution of integrated fisheries and fisheries management.

The key activities in integrated fisheries and management are illustrated in the data flow diagram in figure 2. Although it is not a detailed plan, it still shows the direction for achieving future objectives for fisheries and fisheries management in an economically feasible way.

Data from fishermen, scientists and other sources are accumulated in a Marine Data Centre, where the initial processing takes place that ensures the data quality and put the data into standardized formats suitable for storage and exchanges in a data warehouse. Data are used for

(1) Stock assessment analyses

(2) New research on biology on individuals, population dynamics, species interactions, ecosystem dynamics and ecosystem modelling aiming at improved stock assessment analyses and prognoses

(3) Production of short and long term fishery forecasts (from days to years) with the purpose of easing the fishermen’s organization and optimization of their fisheries. In addition, the fishery forecasts can be used to validate the data foundation and models, because the fishermen will be able to check the accuracy of the predictions.

The basic idea of this proposal is to make use of the commercial fleet for comprehensive collection of data on the current condition of the marine ecosystem. The data collection can be performed as an integrated part of the existing fishing operations and reporting of catch data to the authorities. In connection with the implementation of fully documented fishery, the reporting of catch data will anyway be made at the haul level. In addition to the reporting of catch data, the fishermen are receiving scientific monitoring equipment to measure other important variables in the sea. Thus, the expense of data collection is marginal compared to the yield. Further, receiving an appropriate financial compensation, the fishermen may collect data outside their usual fishing location on their way to, from or between these. The collected information together with data from other sources like scientific surveys, satellites, meteorological and hydrographic models as well as knowledge about the behaviour of marine organisms, are used to develop models that are able to describe the current condition of the ecosystem and forecast the condition at different levels of detail for days or years ahead, including the whereabouts of the fish.

New knowledge on fish behaviour will contribute to innovation within the research area of fisheries technology. Extensive and precise data will minimize the risk of unjustified closures of important areas for the fisheries because of precautionary measures.

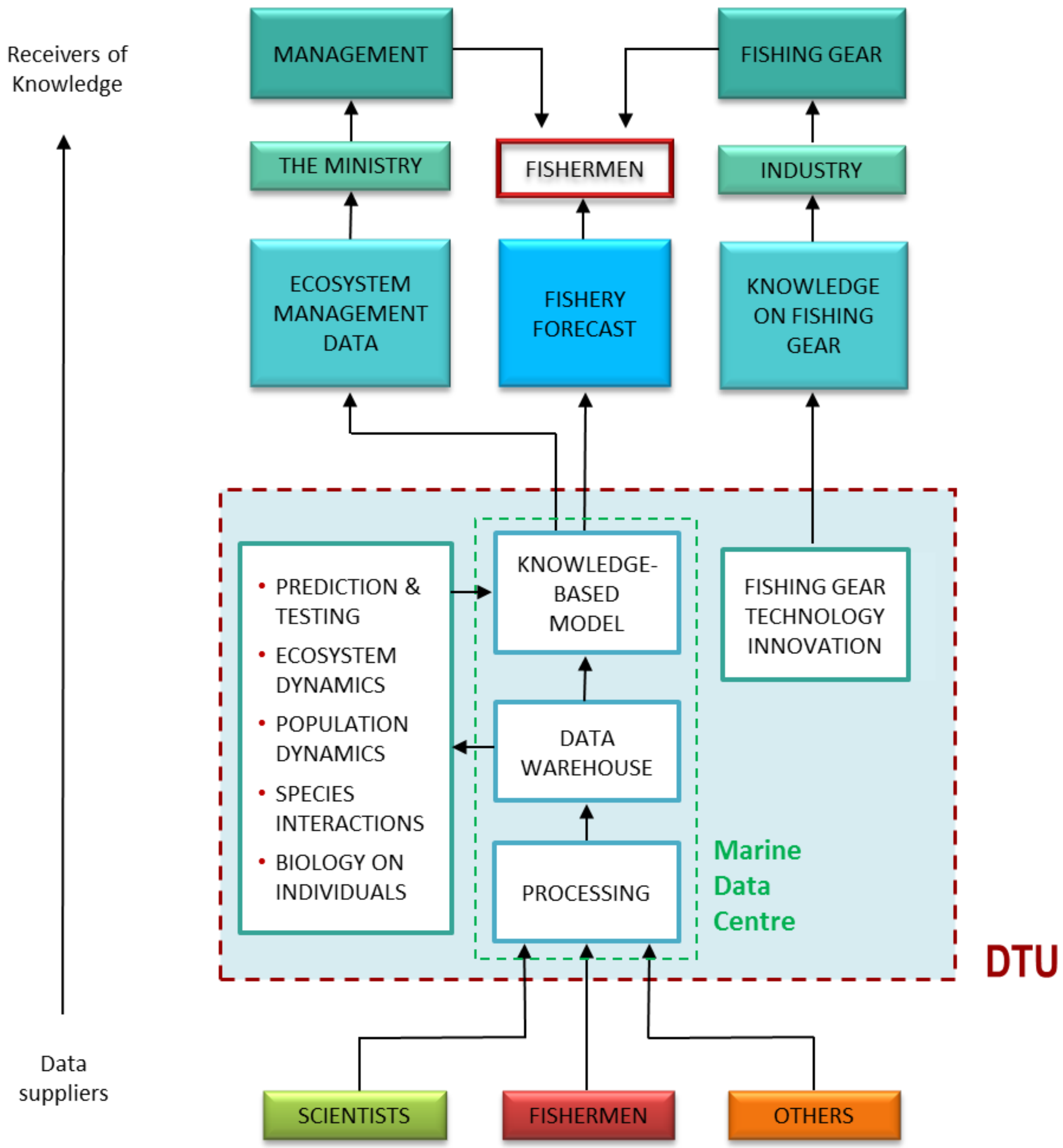


Figure 2. Monitoring programme – Data flow diagram. Establishment of a Marine Data Centre will ensure that large amounts of data obtained from the commercial fisheries are exploited by putting them into standardized formats for storage and exchange in a data warehouse.

References

[1] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)

[2] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (Birds Directive)

[3] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

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[5] Joint Declaration on Discards under a Reformed Common Fisheries Policy, Denmark, France, Germany and the United Kingdom, 1st March 2011

Colophon

Optimization of fisheries resource exploitation in the Skagerrak (Oskar)

By Jan E. Beyer, Maria F. Pedersen, Kai Wieland and Niels G. Andersen (eds.)

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National Institute of Aquatic Resources

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